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ECOLOGICAL STUDIES OF ARAVAIPA CREEK, CENTRAL ARIZONA, RELATIVE TO PAST, PRESENT, AND FUTURE USES

by

W. L. Minckley

Department of Zoology, Arizona State University, Tempe, Arizona 85281

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I. INTRODUCTION

The Sonoran Desert had only a few permanent streams when first colonized by western Europeans, and according to early reports (see Carmony 1978), many of these were even then seasonally intermittent. Yet, the amount and reliability of surface waters were certainly greater in the past than at present, as documented by records of aquatic animals such as beaver (Davis 1973) and fishes (Minckley 1973a), and by the distribution of settlements of native peoples (Haury 1973a).

"Arroyo cutting" in the late 1800s (Bryan 1925, Hastings 1959) initiated major changes in aquatic systems of the American Southwest. This phenomenon, poorly understood and variously attributed to climatic change, overgrazing by livestock, a combination of those factors, or other causes (Hastings and Turner 1965), resulted in incision of watercourses and massive degradation of floodplains. Marshy areas paralleling streams and rivers, extensive "ciénega" habitats that resulted from aggradation-inducing events such as damming by beaver, ponding behind natural levees, and so on, were lost or greatly reduced in extent. Buffering effects against drought by high water tables adjacent to flowing channels were thus eliminated, and intermittency became more frequent and severe.

Man's direct modifications commenced in ernest about the turn of the present century. Early agricultural peoples had practiced extensive and successful irrigation (Haury 1936, 1976). Bartlett (1854) reported the entire Gila River as being locally diverted to agricultural lands by Indians. However, their dams leaked, and more importantly were over-ridden and breached by each spate, so that integrity of downstream riverine environments was assured.

Beheading the desert segment of the first large southwestern river system was accomplished in 1913 with closure of Roosevelt Dam on the Salt River, central Arizona. Several other major dams followed, so that lowland parts of major streams in the region now function only as delivery systems, or are maintained by wastewater discharge (Brown et al. 1978).

Pumpage of substantial amounts of groundwater started a bit later than dams. That practice accelerated de-watering of stream channels and extended to ever smaller watersheds as technology increased and demands rose with expanding populations. Pumpage now exceeds rates of recharge by many tens of meters in some drainages, precluding surface flow in most desert channels except during flood.

In places where surface waters remain, introductions of non-native plants and animals present additional ecological problems. Saltcedar (principally *Tamerix chinensis*) has spread to infest riparian zones of essentially all desert waterways, whether permanent or ephemeral (Robinson 1965, Horton 1977), and many native riparian plants have ceased to successfully reproduce (Turner 1974). Few indigenous fishes persist in reservoirs (Minckley 1973a), and those which do regularly fail to reproduce and ultimately disappear. Direct predation by young and adults of introduced kinds seems the mechanism for extirpation of native fishes, both in artificial reservoirs and in natural systems (Minckley et al. 1977, Minckley 1979a).

The subject of the present report, Aravaipa Creek, Graham and Pinal counties, Arizona, has not been immune to change. In reaches not protected by bedrock, incision of the channel is apparent. Ciénegas no longer exist as parts of the system. It has long been used for irrigation within the relatively narrow valley, and diversion dams of mounded sand and gravel similar to

those constructed in the past by Indians are periodically built, resulting in desiccation of short reaches of stream. Introduced fishes, although present, remain rare, saltcedar has yet to make a substantial invasion, and much of the native biota to be expected in such an area is intact. I commenced studies of the stream in 1964, along with numerous graduate students and colleagues, and here report qualitative and quantitative results for 1964 through 1978, with emphasis on the last three years of that period. Sections of this report not specifically written by me are so indicated in text, but I exercised editorial perogative and any errors, omissions, or misinterpretations are my responsibility.

II. DESCRIPTION OF THE AREA

A. Topography and Geology

The Aravaipa Creek watershed begins at a low divide in the northwest end of the Sulphur Springs Valley. The channel[1] follows local geologic structure to trend northwest, north of the Galiuro Mountains and south of the Pinaleño and Turnbull-Santa Teresa ranges, then turns west to deeply dissect the northern flanks of the Galiuros and enter the San Pedro River south of the town of Winkleman (Fig. II-1). The watershed comprises about 1,400 km^2 (ca. 541 square miles).

Although the channel of Aravaipa Creek begins at about 1,400 m above mean sea level, perennial flow now originates from unconsolidated sediments of the stream bed between 1,010 and 1,080 m (depending upon the year) 6.4 to 5.5 km

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[1] As used here, "channel" refers to the portion of the system scoured of perennial vegetation by flooding, while "floodplain" includes alluvium along the stream that in the case of Aravaipa Creek is bounded by stony terraces or cliffs (definitions modified from Burkham 1972).

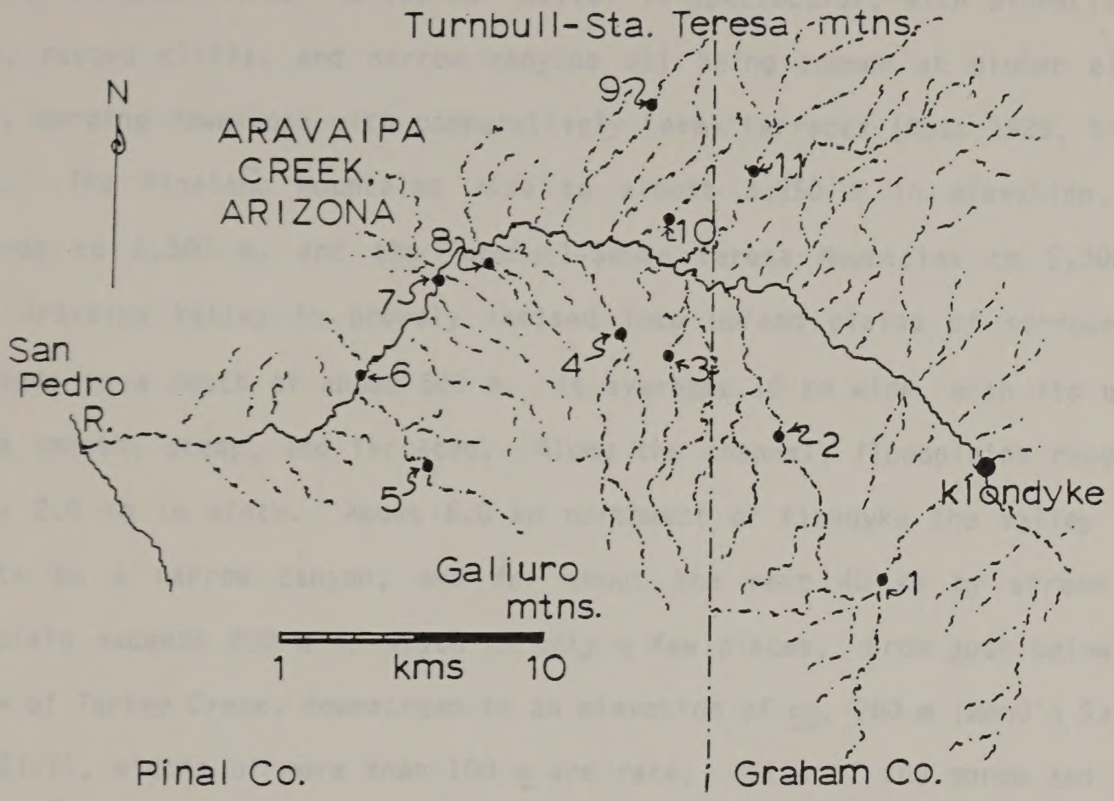


Figure II-1. Sketch map of the Aravaipa Creek basin, Graham and Pinal counties, Arizona, showing some features mentioned in text. Symbols: 1 = Four-mile Creek; 2 = Turkey Creek; 3 = Parson's Canyon; 4 = Virgus Canyon; 5 = Holy Joe Canyon; 6 = J. White Ranch; 7 = Wood's Ranch; 8 = Hell's Half-acre Canyon; 9 = Horsecamp Canyon; 10 = Paisano Canyon; and 11 = Hellhole Canyon.

northwest of the town of Klondyke. Elevation at the confluence of the creek and the San Pedro River is 652 m. Relief is spectacular, with pinnacles of stone, rugged cliffs, and narrow canyons all being common at higher elevations, merging downslope with comparatively level terraces (Ross 1925, Simons 1964). The Pinaleño Mountains rise to almost 3,350 m in elevation, the Galiuros to 2,300 m, and the Turnbull-Santa Teresa Mountains to 2,300 m. Upper Aravaipa Valley is broadly incised into upland plains of surrounding highlands to a depth of about 500 m. It averages 10 km wide, with its upper slopes smooth, steep, and terraced. Along the channel, floodplains range to nearly 2.0 km in width. About 6.0 km northwest of Klondyke the valley constricts to a narrow canyon, and for about the next 40 km by stream the floodplain exceeds 400 m in width in only a few places. From just below the inflow of Turkey Creek, downstream to an elevation of *ca.* 760 m (Wood's Ranch; Fig. II-1), widths of more than 100 m are rare. Walls of the gorge and some of its tributaries rise vertically for 200 m or more, and the channel occupies the entire canyon bottom in places as narrow as 30 to 40 m. Downstream from 760 m elevation the canyon widens progressively to finally pass across the floodplain of the San Pedro River.

Geology and geologic structure of the Aravaipa Creek area are locally confusing, but do not seem overly complex (Simons 1964). Basin and Range physiography of the area has three major elements: 1) the Galiuro Mountain block, consisting of a thick pile of Tertiary and perhaps Cretaceous volcanics and minor amounts of older sedimentary and igneous deposits; 2) Aravaipa Valley, underlain by conglomerate and alluvium of Tertiary age and Quaternary alluvium; and 3) the Santa Teresa and Turnbull Mountain blocks, made up of

Tertiary granites and a mixture of sedimentary, igneous, and metamorphic rocks of various ages.

The present arrangement of mountains and valleys was likely established prior to deposition of the Hell Hole Conglomerate of Middle or Late Tertiary age (Simons 1964). This rock is composed mostly of angular to rounded fragments from gravel to boulder size, embedded in a sandy matrix, and was apparently deposited through erosion of the Galiuro Mountain block northeastward into a structural trough now occupied by Aravaipa Valley. Another layer was deposited over the Hell Hole Conglomerate in Late Pliocene or Pleistocene times (Simons 1964). Termed "Older Alluvium," this deposit originated from the Santa Teresa block to the north and east, and is continuous into the Sulphur Springs Valley and around the southeast end of the Pinaleño Mountains into valleys of the San Simon and the Gila rivers, where it has been generally termed the Gila Conglomerate (see review by Clarkson 1979). Terrace and lake deposits along upper Aravaipa Creek "presumably are of recent age, but may be as old as Pleistocene (Simons 1964)."

Aravaipa Creek was considered by Melton (1960) to represent part of an "old drainage" of Arizona, a system of northeast-southwest trending drainageways that incised and thus persisted through Basin and Range development, thus providing antecedent channels for integration of the present network of watercourses. Simons (1964) outlined the development of Aravaipa Creek in a manner that generally fits the same scheme, as is quoted below:

> 1. Deposition of older alluvium along a north-northwest-trending valley or basin. The present site of Aravaipa Valley was evidently a broad alluviated area, perhaps not having external drainage. The Galiuro Volcanics must have extended farther west than at present, possibly covering what is now the valley of the San Pedro River.

2. Beginning of uplift of the Galiuro Mountains block together with the alluviated valley, on a Basin and Range fault along the west flank of the range. Uplift at first was greater north and south of the present Aravaipa Canyon than at the canyon site, so that a broad east-trending synclinal warp was formed, its trough approximately along Aravaipa Canyon. If external drainage existed previously, downstream slopes of ancestral Aravaipa Creek were reversed by the differential uplift; the master stream may have been diverted westward toward the synclinal trough, or a closed basin may have formed temporarily east of the Galiuro Mountains.

3. Erosion of Aravaipa Canyon initiated either by overflow from a closed basin at the low point on its west rim or by the diverted ancestral Aravaipa Creek. At this stage the Aravaipa may have been flowing at an altitude not greatly different from its present altitude but a thousand feet or more higher in the stratigraphic section. The major tributaries of the Aravaipa probably came into existence at this time as watercourses consequent upon land surfaces sloping toward Aravaipa Canyon.

4. Continued uplift of the Galiuro Mountains. During this uplift, Aravaipa Creek was able to maintain its westerly course--in other words, it was antecedent to the later period of uplift--and cut its present canyon. The fault-block origin of the Galiuro Mountains and the antecedent nature of the present course of Aravaipa Creek were suggested long ago by Davis and Brooks (1930). The southwest-sloping tributaries of the Aravaipa, being, with the exception of Old Deer Creek, rather short and having small catchment basins, have not been able to keep pace with the downcutting of Aravaipa Creek, and their junctions with the master stream are strongly discordant. On the other hand, north-sloping tributaries are longer, have larger catchment areas, and probably receive more rainfall in their high headwaters, and consequently now have accordant junctions with the Aravaipa.

Following this major downcutting, Aravaipa Creek above the gorge widened its floodplain and cut steep bluffs in the Older Alluvium and Hell Hole Conglomerate. At present it flows on its own alluvial deposits. At some time during cutting of the present floodplain, the stream must have been blocked near the present source of perennial water, forming a lake several kilometers long in Aravaipa valley. This lake persisted long enough to deposit more than 30 m of sediments, most of which have now largely been removed by erosion (Simons 1964).

B. Climate

Two major weather stations provide relatively long-term records near Aravaipa Creek -- the Fort Grant station at 1,486 m elevation near the upper end of Aravaipa Valley, and Dudleyville (Winkleman) station at 632 m near the mouth of the stream (Green and Sellers 1964). Records for Klondyke, although also of relatively long term, have substantial gaps and have yet to be officially summarized (U.S. Weather Bureau, published periodically). As for most of southeastern Arizona (Lowe 1964), climate of the area is mild, and a pattern of spring drought, summer monsoons, then more regular winter rainfall is strongly developed (Fig. II-2, Table II-1).

At Fort Grant, almost 50% of the mean annual precipitation of 31.92 cm falls in the period from July through September, resulting from an influx of warm, moist air from the southeast. Instability of air masses along the Pinaleño Mountains results in moderate to violent thunderstorms, typically in afternoon and early evening. More than 8.0 cm of rainfall has been recorded from one of these storms. Winter precipitation, only a small fraction of which occurs as snow, results from Pacific airmasses entering the area from the west. High mountains such as the Galiuro block intercept some of this moisture, and winter rainfall is therefore less than might be expected at almost 1,600 m. Temperatures at Fort Grant rarely drop below freezing for more than a few hours at night in winter, and summer temperatures rarely exceed 32.2^{0} C. Winter and Summer extremes are ameliorated by position of the station above the floor of the valley, and are undoubtedly greater a few meters downslope (Green and Sellers 1964).

Dudleyville has an average annual precipitation of 37.44 cm, 5.5 cm greater than that at Fort Grant despite its lower elevation and more western

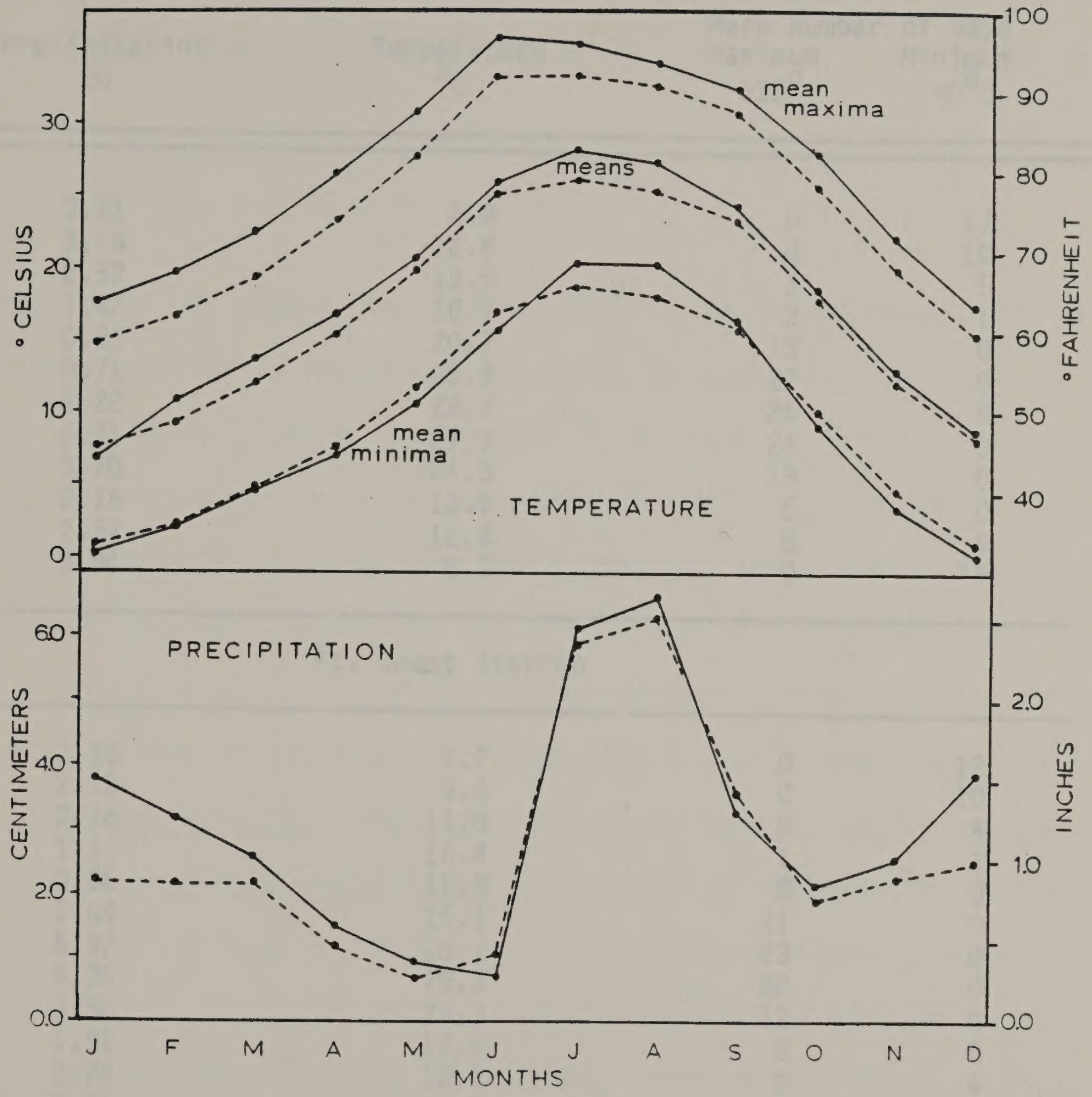


Figure II-2. Average monthly temperatures and precipitation at two stations in or near the Aravaipa Creek watershed. Dotted lines connect data for the Dudleyville (Winkleman) station, Pinal County, Arizona, and solid lines are for Fort Grant station, Graham County.

Table II-1. Summary of climatic conditions at Dudleyville (Winkleman), Pinal County, and Ft. Grant, Graham County, Arizona (Green and Sellers 1964).

Dudleyville Station

Months	Precipitation	Temperature	Mean Number of Days	
	cm	°C	Maximum >32°	Minimum <0°C
J	3.81	8.9	0	17
F	3.18	12.8	0	10
M	2.57	13.6	3	5
A	1.47	16.8	3	1
M	0.91	20.7	13	0
J	0.71	25.9	27	0
J	6.22	28.2	26	0
A	6.71	27.3	24	0
S	3.20	24.3	19	0
O	2.16	18.5	6	0
N	2.57	12.8	0	6
D	3.94	8.7	0	18

Ft. Grant Station

Months	Precipitation	Temperature	Mean Number of Days	
	cm	°C	Maximum >32°	Minimum <0°C
J	2.18	7.7	0	12
F	2.13	9.4	0	10
M	2.18	11.8	0	4
A	1.17	15.4	1	1
M	0.66	19.8	5	0
J	1.04	25.1	21	0
J	5.97	26.1	23	0
A	6.35	25.3	20	0
S	3.58	23.3	12	0
O	1.91	17.8	2	0
N	2.24	12.1	0	4
D	2.51	8.2	0	14

position. This results from substantially greater winter precipitation from east-moving Pacific storms that contact the Galiuro - Turnbull mountains and release their moisture downslope. Temperatures trend higher at the Dudleyville station in summer, often exceeding 43° C, and freezing temperatures are common in early morning hours in winter (Table II-1).

C. Vegetation

by William G. Kepner

Aravaipa Creek is within the Sonoran Desert, which includes much of southern Arizona. Source of the stream is within the Upper Sonoran Life-zone, which ranges from about 1,100 m in elevation to as high as 2,100 m, and includes grassland, chaparral, and open woodland communities (Lowe 1964). The flora is diversified in physiogamy and rich in species (See Appendix A).

The environs of upper Aravaipa Creek are best characterized as desert-grassland. This is a highly diversified community where grasses are co-mingled with various shrubs such as yuccas (_Yucca_ spp.), sotol (_Dasylirion wheeleri_), jojoba (_Simmondsia chinensis_), and beargrass (_Nolina microcarpa_), and where juniper (_Juniperus monosperma_) is scattered on north-facing slopes. This community most generally occurs on shallow-soiled, gravelly to rocky hills and slopes. It often represents a grass-dominated transition between either open woodland or chaparral above and desert-scrub below. As a transitional area, desert-grassland typically receives between 25.4 and 38.1 cm of annual precipitation and occupies Arizona landscapes from just below 1,100 m upward to approximately 1,500 m (Lowe and Brown 1973).

Downstream along the creek, desert-grassland grades into desert-scrub of the Lower Sonoran Life-zone. In Arizona, total annual precipitation and

elevation within this zone usually range from 7.6 to 25.4 cm and from 30 to approximately 1,200 m, respectively, according to slope exposure.

Lower Sonoran desert vegetation represents approximately 9% of the Arizona flora ($\approxeq$ 300 species) and is most widely characterized by two principal life-forms: 1) open, well-spaced microphyllous shrub vegetation that is either predominant or exclusive; and 2) spinose, succulent and/or microphyllous, short-tree vegetation, collectively called desert-scrub (Kearny *et al*. 1960).

The first is most clearly represented by creosote-bush (*Larrea divaricata*) communities in which trees are usually absent and shrubs and dwarf shrubs are dominant and widely scattered. This is a climax community, which is characteristically on soils of fine texture and often alkaline, and which usually inhabits area of low relief, *i.e.* the desert floor.

The second is most often represented by, but not restricted to, paloverde-saguaro (*Cercidium*-*Cereus*) communities. In this community, plants are comprised of small-leaved trees, as well as shrubs and numerous cacti. Best development is attained on rocky hills and coarse-soiled slopes, *i.e*. the "*bajada*," where substratum is on or near parent bedrock. Plant morphology is highly diverse, with leafless, drought-deciduous, and evergreen species. Community biomass and productivity are greater here than in creosote-bush communities on valley-fill substrates of the plains below. Shrubs are more varied than trees, and although the foothill understory may be predominantly of a single species, *e.g.* triangle-leaf bursage (*Ambrosia deltoidea*) or brittlebush (*Encelia farinosa*), it is often comprised of a mixture of 5 to 15 or more shrub and dwarf-shrub species in the form of a layered understory.

Riparian habitats are distinct biotic communities associated with perennial or intermittent watercourses. They are unique reservoirs of plant and animal diversity that extend from desert-shrub of the Lower Sonoran zone to fir forests of the Canadian Life-zone. These habitats consist of different life-forms or species than those of the immediately surrounding, non-riparian climax (Dick-Peddie and Hubbard 1977). Riparian communities in Arizona have been reduced or eliminated by past and present land management practices to the point where it is estimated that total riparian area comprises only 1,131.53 km^2 within the state, of which 407.53 km^2 are adjacent to the mainstream Gila River (Babcock 1968).

Following the classification outlined by Brown and Lowe (1974), vegetation along the immediate banks of Aravaipa Creek best represents the Temperate Riparian Decidous biome, a warm-temperate, winter-deciduous woodland. Because riparian communities generally exhibit a predictable vertical zonation where composition and form of riparian woodlands changes with elevation (Campbell and Green 1968), this biome may be subdivided into two major communities -- Mixed Broadleaf and Cottonwood-Willow (*Populus-Salix*).

Mixed broadleaf communities usually are along rubble-bottomed perennial and semi-perennial streams are presently characterized in upper Aravaipa Valley by a canopy of cottonwood (*Populus fremontii*), willow (*Salix* spp.), sycamore (*Platanus wrightii*), velvet ash (*Fraxinus pennsylvanica velutina*), walnut (*Juglans major*), and box elder (*Acer negundo*), with a thick, luxuriant understory. Wild grape (*Vitis arizonica*) often provides additional vegetative cover. A continuum condition exists, where broadleaf species occur throughout the drainage, but are most prevalent at the upper reaches.

Although no discrete downstream boundaries exist among species aggregations, vegetation grades within the narrow Aravaipa Canyon into a community dominated by cottonwood and willows (Salix gooddingii and S. bonplandiana). The understory may be a dense stand of riparian tree regeneration, or shrubs, to relatively open and park-like areas. Willows, principally Salix gooddingii, greatly outnumber cottonwood, and seepwillow (Baccharis salicifolia) is the principal shrub of the understory. Watercress (Nasturium officinale) and rare cattail (Typha sp.) grow in the creek along with algae. The last plants demonstrate marked seasonal trends of abundance and consist mostly of encrusting diatoms (Bacillariophyceae) and filamentous Cladophoraceae (Cladophora glomerata) (Bruns and Minckley 1980).

At the lower reaches, floodplains are vegetated by winter-deciduous microphylls, e.g. mesquite (Prosopis velutina) and catclaw (Acacia greggii), which form a distinct border association separating riparian and desert-scrub climax communities. This transitional vegetation zone is often classified as a distinct community, the Subtropical Deciduous Woodland Biome. Within the Sonoran Desert, it is largely restricted to elevations below 1,067 m where maximum development is attained on alluvium of old floodplains (Brown and Lowe 1974). In the past, annual and perennial grasses and herbs formed the ground cover within mesquite-dominated bosques, and the understory was relatively open. But today, on the Aravaipa floodplain and elsewhere, introduced annual forbs such as heron-bill (Erodium cicutarium), mustards (London skyrocket, Sisymbrium irio), and grasses, especially Bermuda grass (Cynodon dactylon), red brome (Bromus rubens), and Mediterranean grass (Schismus barbatus), are more frequently encountered. Invasion by saltcedar from the San Pedro River floodplain is threatening Aravaipa Creek, and its aggressiveness may soon

allow it to outcompete native riparian species such as seepwillow and burrobush (Hymenoclea monogyra).

III. HISTORICAL REVIEW

Historical information on the ecology of Aravaipa Creek and its watershed is remarkably scattered and difficult to obtain. Bell (1869) produced an excellent account of the upper valley, canyon, and surrounding terrain, and implied that the area was well known and often visited in the middle 1800s. Yet only a few additional accounts were discovered. Data provided by Hastings (1959) and Hastings and Turner (1965), however, allow considerable interpretation of changes in aspect of aquatic, semi-aquatic, and terrestrial environments in southeastern Arizona in the past 100 years, and undoubtedly apply to the Aravaipa region.

First incursions by Caucasians into the area of Aravaipa Creek were explorations by Francisco Vasquez de Coronado in the late 1530s and early 1540s. According to Olmstead (1919), the route used by that force in moving northward to the Gila River descended the San Pedro River Valley to Tres Alamos Wash, then passed into Sulpher Springs Valley, presumably to traverse the broad divide separating the Santa Teresa and Pinaleño mountains. They must therefore have passed at least through headwaters of Aravaipa Creek (Fig. II-1). In the 1600s and early 1700s, movements north by Jesuit priests and mission missionaries into the area of what now is Arizona scarcely extended to the Aravaipa area. Recall of the Jesuits to Spain in the mid-1700s, along with ever-increasing hostilities between Apaches and Spaniards, forced settlers back toward the south or into armed enclaves, and further limited settlement of the area (Minckley 1979b).

The war of independence between what is now México and Spain further interrupted orderly immigration in the early 1800s. Settlements were few or non-existent, and only trappers traveled through the area. In 1825, Pattie (1962) trapped beaver along the Gila River and its tributaries in eastern Arizona, and ascended the San Pedro River to cross the Galiuro Mountains to the Sulphur Springs Valley. No mention was made of Aravaipa Creek or Canyon (Davis 1973), but Pattie described other riparian habitats that must have resembled those along that stream (reviewed by Minckley 1979b).

Early reference to Aravaipa Creek in older literature and reports were largely a result of explorations for wagon or railroad routes. Leach (1858) recorded stream conditions in southern Arizona in 1858, including observations that no surface flow was present at the mouth of Aravaipa Creek, nor in the lowermost San Pedro River, conditions that often occur today. Hutton (1859) reported that Aravaipa Creek originated in a large marsh about 8.0 km upstream from the canyon, and Bell (1869) may well have illustrated that marsh in a lithograph (from a photograph). Bell, traveling at night over the divide between Sulpher Springs Valley and the uppermost Aravaipa Creek drainage, provided the following information:

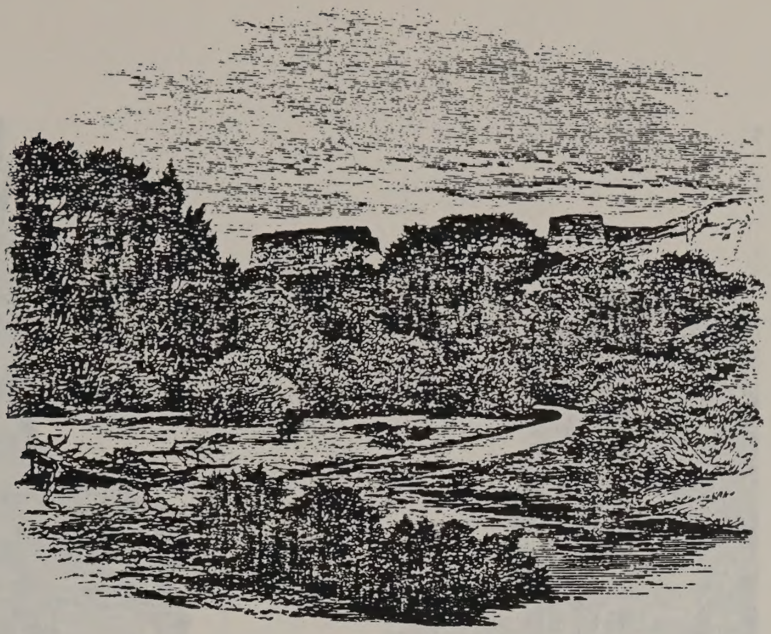
> At last we came to a sudden depression or groove in the centre of the valley; the land had sunk from beneath, and formed a second little valley at the bottom of the first. This was the commencement of the cañada of the Aravaypa. We descended into it, and followed along the dry, grass-covered bottom until the sides had assumed the magnitude of bluffs. The ground became more fertile; brushwood, and even willows, grew in places; and soon a well-defined water-course could be made out running along one side of us.

This area is almost certainly in or near Section 30, Township 9 south, Range 22 east. Bell and his party then recorded Eureka Spring (near the present Eureka Ranch) as "warm and sulphurous, and neither fit for man nor beast." They traveled 10 additional miles (16 km) on about 17 November 1867, and:

> ...encountered a large spring, which bubbled up from the ground in the centre of the cañada; from it flowed a perennial stream of considerable volume, whose life-giving waters filled the valley below this point with thick luxurient vegetation.
>
> ...we dashed through the rivulet into the thick grove of cottonwoods...what pleasure it was to see once more around me trees and flowers, to listen to the song of birds, the rippling of waters, and the subdued rustling of the leaves overhead...

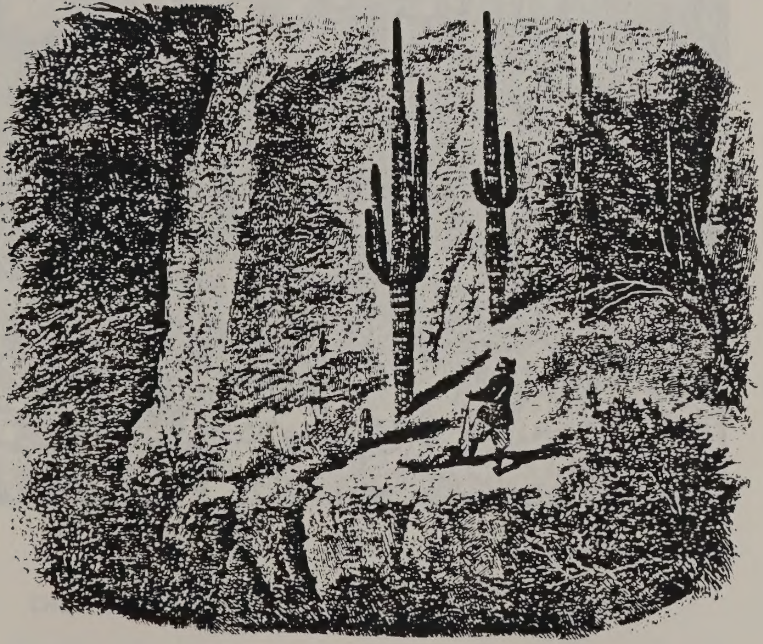
Accuracy of Bell's observations may be assessed by the following resume of his observations on the upper valley (Bell 1869: pp. 61-62; see also Figs. III-1 - III-3):

> After descending from Railroad Pass to the centre of the trough (six and a half miles), and on changing our course towards the northwest, we do not continue to descend; but, on the contrary, in the first twenty-two miles we rise again some 200 feet. At about this point we cross a divide, and commence the real descent towards the Rio Gila; or, in other words, we enter the basin of the Aravaypa. This fact is soon made manifest by the appearance of the cañada of the Aravaypa as a groove at the bottom of the trough between the mountains. From the commencement of this cañada to the point where its walls approximate so closely as to form the canon proper the distance is 25.30 miles, in which interval the total descent is 1,104 feet.
>
> As this great fall does not represent the slope of the trough between the mountains, but the gradual deepening of the groove in its centre (the cañada of the Aravaypa), it is easy to understand how the cliffs or sides of the cañada become higher and higher as we descend. Sometimes they approach each other, and form a natural gate or narrow passage for the river bed. Sometimes they recede to the distance of two or three miles apart. In places they have perpendicular walls. Often they become sloping banks, and being composed of soft, friable material, mostly drift, they are sometimes transformed by erosion into very picturesque objects, resembling forts, castles, long lines of earthwork, and the like, which are chiefly remarkable for the mathematical regularity of their outlines, thus giving a very peculiar appearance to the whole country, since the traveler is never out of sight of these singular formations; for no sooner is one passed then another appears at the next turning of the gorge. At the back rise the black shining walls and the deeply-serrated summits of the volcanic ranges on either side. These gradually approach each other until the trough itself becomes obliterated, and the walls of the cañada in its centre are of necessity merged into the mountain sides. At the point where the mountains seem to unite, the cañon proper begins.



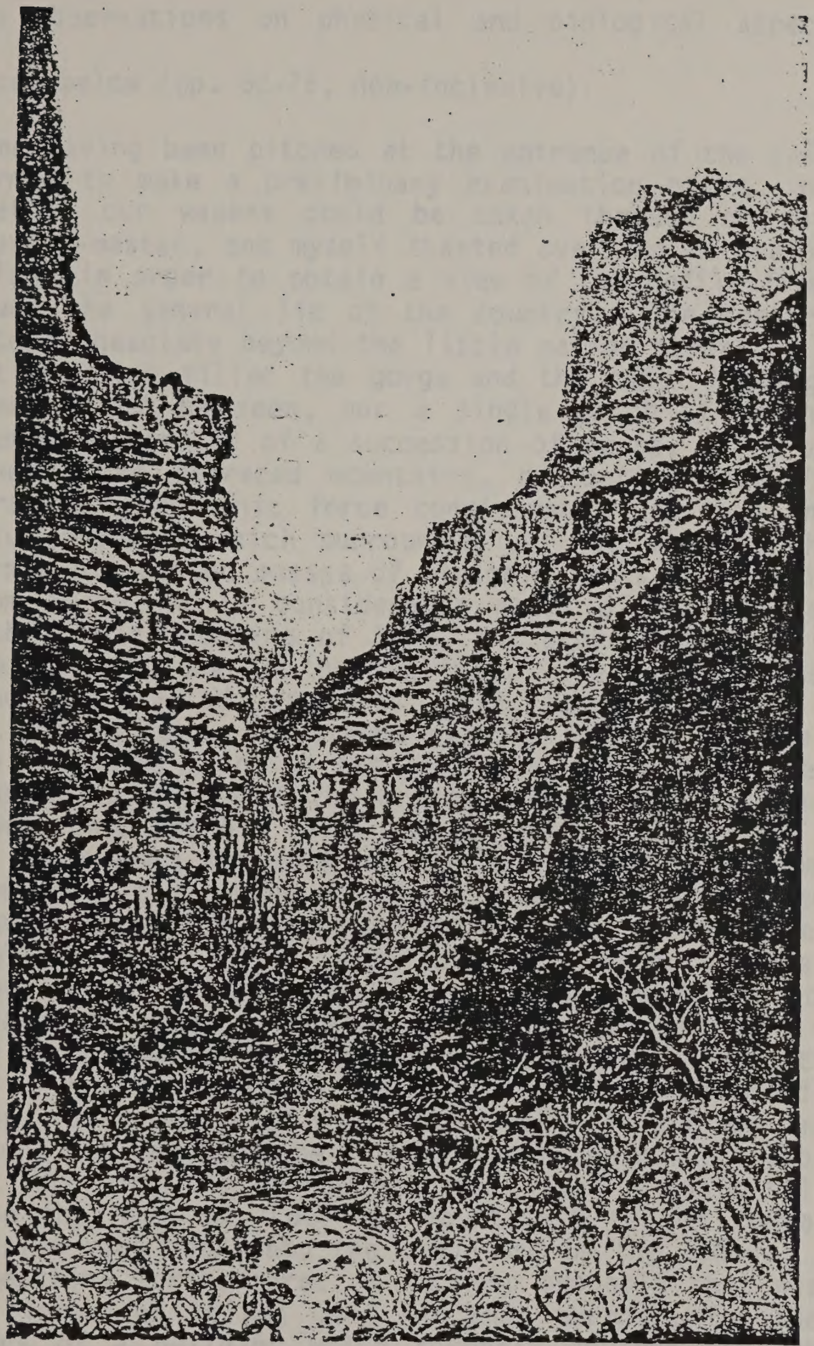
Our First Camping Ground.

Figure III-1. Lithograph from Bell (1859) of Aravapia Valley.



The Cereus giganteus.

Figure III-2. Lithograph from Bell (1869) of Aravapia Creek.



Vincent Brooks Day & Son Lith.

THE ARAVAYPA CAÑON. SOUTHERN ARIZONA

Figure III-3. Lithograph from Bell (1869) of Aravaipa Creek

Bell and his party spent 5 days in Aravaipa Canyon (22-26 November 1867), and his observations on physical and biological aspects of the area are reproduced below (pp. 62-76, non-inclusive):

> Camp having been pitched at the entrance of the cañon, a party was formed to make a preliminary examination of it, and to determine whether our wagons could be taken through or not...Stuart, our quarter-master, and myself started over the Mountains upon two good mules, in order to obtain a view of the defile from above, and to study the general lie of the country. The scenery was wild and utterly desolate beyond the little narrow streak of beautiful vegetation which filled the gorge and the cañon leading to it. Not a tree was to be seen, nor a single patch of green. The country seemed to consist of a succession of mesas, piled up one above the other, like terraced mountains, presenting from five to a dozen parapets. Volcanic force considerably assisted in producing the wild confusion which surrounded us; for many of the summits were formed of pointed masses of plutonic rocks which had been forced up from below, while considerable areas of surface had been covered with a thick coating of lava, the broken edges of which shone out smooth and black in the sunlight. The most prominent mass in the landscape--called, from its shape, Saddle Mountain--is probably an extinct volcano. It stands exactly in front of the trough between the mountains which we had left, and seems to be the chief obstruction which prevented the Aravaypa River from continuing its direct course into the Río Gila, and obliged it to deviate from north-west to south-west; for looking over the dreary landscape in the latter direction, the rugged outline of the mesa country seemed to us less obstructed by formidable barriers on that side; while at our feet we could trace for miles the black cleft in the earth's crust which we knew to be the Aravaypa Cañon. With a good deal of climbing, we managed to enter a side gorge which debouched upon the main canon, and by following its windings at last entered the latter about three and a half miles from its head, and then followed its course to camp, fully persuaded that if the cañon itself was impracticable for wagons, no way could be found through the country above it.
>
> Guarding the narrow entrance rises a conic hill, to which we gave the name of "Look-out Mountain," for it commands a very extensive view both into the cañon and up the cañada, in the opposite direction; furthermore, it is most probably that when this country was inhabited it was used for that purpose, for the stone foundations of a building which formerly covered the summit are still distinctly visible. Close under this hill a very large spring gushes out of the ground, the waters of which more than double in size the Aravaypa stream. Without this large permanent supply of running water the cañon could probably never have been formed.
>
> For the first two miles the walls are perpendicular on one side, and sloping on the other; the former do not exceed 500 feet in height; but at the end of that distance a large triangular mass juts up from the centre of the ravine, which seemed to us to bar all

further progress. The stream, however, had managed to twine around it, and by following in its bed we succeeded in doing so too.

From this point the walls on both sides are perpendicular. They are formed for the first few miles of conglomerate alone, which is horizontally stratified; in fact, drift-washed down by primeval waves from the mountain's side. But as the gradual fall of the stream bed, which is on an average 50 feet per mile, brought us deeper into the earth, we reached the sandstones, and gradually passed through them to the hard granite beneath. Luxuriant vegetation fills up the space between the walls; the undergrowth consists of willows, young trees, bunch grass, reeds, &c., forming in many places an impenetrable thicket; and above them a succession of noble trees tower up towards the sky, as if striving to gain a glimpse of the upper world. Under a grove of the loftiest cottonwoods and sycamores, at a distance of four miles from the head of the cañon, we threw down our blankets for the first night's rest. Not far distant, a few deserted Indian wigwams were visible, perched upon the top of the cliff, which painfully reminded us of danger. The setting sun beautifully illuminated three Norman watch-towers, which some freak of nature had carved out upon the precipice that rose above our grove of trees.

The obstacles our surveyors had to contend against naturally made our progress very slow, not more than from two and a half to three miles per day being cleared; for a path had to be cut through the brushwood which choked up the narrow passage, and every tree obstructing the vision of the levelers had to be felled. The Mexicans whom we had picked up were of great assistance to us. We hired six of their animals for pack mules, and several of the men to help as axe-men in cutting a path through the thickets... During the second day's advance we came to a cave, hollowed out in the northern wall, capable of concealing about fifty men,... Apaches had carried on agriculture to some extent in the cañon, for we passed the remains of a few small irrigating canals in places where the space between the walls left a sufficient extent of bottom-land for such a purpose.

As we advanced, the cañon became more and more tortuous. Bold walls of rock often enclosed us in front and rear, as well as on either side; nor could we tell which way to turn until we had come close upon the apparently insurmountable barrier. Higher and higher towered the walls. For the first few miles they were flat and continuous from base to summit, although portions here and there stood out like hugh needles or lofty spires from the main cliffs; but after attaining a certain height, the walls became divided into two, the upper portion of which seemed to lean a little back and to rise from the lower one, like a cliff springing from a cliff. The walls, in fact, became two stories high, and each story measured about 400 feet. The strata of the upper story or cliff continued, as before, to consist of conglomerate; but grey sandstone appeared at the base of the lower one, and gradually extended upwards. Caves and grottoes became very numerous, and every mile added to the grandeur of the chasm.

The stream had to be crossed over and over again--often at every hundred yards; and it was curious to see how active the little axe-men of nature, the beavers, had been, for many a wetting was saved by our men on foot being able to cross over the large trees which, having been felled by these little fellows, had fallen athwart the stream. Nor were beavers the only inhabitants. Deer came down to drink at the brook, but by what paths remained a mystery to us; quails and doves were very abundant in places; and birds with beautiful plumage--some bright red, others rich blue, and a third variety, a black and white kingfisher with a bright red crest--especially attracted our notice...a fine flock of turkeys had so tempted the foremost of our party, that, forgetful of the alarm they would cause, they had seized their rifles and fired at them...

About seven and a half miles from the entrance, the cañon becomes so narrow that it appears only as a cleft between the huge perpendicular walls which tower above: there is no space whatever on either side between the bed of the stream and the rocks, so that the only passage is in the river itself. The action of the water, moreover, has hollowed out the base of the southern wall-rock for from 20 to 30 feet of its thickness, so that we rode under the rock itself for some distance.

The first "narrows," as we called this passage, having been passed, we came to an open space of some fifteen acres, giving us a good camping ground and plenty of grass for the stock. This space is situated about the centre of the canon, and is very beautiful, being filled with splendid timber, cotton-wood, sycamore, live oak, ash, willow, walnut, and grotesque old mezquites of most unusual size. Fine branches of mistletoe hung from many of the trees...
Just past this open space a great change takes place. In order, it would almost seem, that the traveller should not weary of cold grey sandstone and conglomerate formations, the sombre tints and horizontal strata, large quantities of volcanic rock, with their smooth facets and their rich tints varying from purple and red to black, burst into view, and alter completely the appearance of the walls. A deep rich fringe of basaltic columns adorns the terraces on either side, and this lavaform coating is bright and shining; the edges are as sharp in outline as if cut with a knife, and produce fantastic forms in the shape of turrets, &c., quite different in appearance from those met with previously. Nor is the change to be seen only in the rocks--the vegetation immediately shows the difference of soil; and, identical in position with the new strata, appeared for the first time on our route the Cereus giganteus, the largest cactus with which botanists are acquainted. Here these huge grooved columns thrust their thick trunks from between the crags, and rise up on all sides far above our heads to heights varying from the baby-plant to the forty-feet. They seem to require no earth; and in places the walls are covered with them to the very summit. The secondary columns shoot out from the central stem, and then turn upwards with studied regularity, forming a circle of four or six arms around the parent trunk. Besides the "Monumental Cactus," as it is sometimes called, large bushes of prickly pear, tufts of Spanish bayonet and magay, with other species of prickly plants,

also find a genial abode up amongst the crags, producing a contrast most singular and striking between the grotesque spinous vegetation upon the walls and the graceful foliage in the narrow passage beneath.

A little further, the rocks on either side approach so closely as to obliterate for a second time the entire passage, and this time the bed of the stream alone remains between the walls for two miles and a half of its course. At this part the walls present another break in their perpendicular height, and appear to consist of three terraces of cliffs piled one above the other, each capped with basaltic columns; thus showing, as it appears to me, the real nature of the terraced form. Each cliff or terrace is, in fact, a land-slip into the gorge, the lowest terrace representing the part earliest detached; for as each terrace is covered with lavaform basalt, it is evident that at some time each ledge so covered must have formed part of the surface of the ground over which the lava had flowed.

Between the two "narrows" the cañon did not widen much, so that the lengthening shadows overtook us very early in the evening, and obliged the surveyors to cease from their work; and when the sun had left the upper world, and night had really come, the blackness of darkness around us was absolutely awful, and the stars, which covered the narrow streak of sky above, seemed to change the heavens into a zigzag belt, every inch of which was radiant with diamonds. Our camps, too, were very picturesque. The mezquite tree, with its tortuous stems, grows to an unusual size here, and as the wood makes magnificent fuel, we found the foot of one of them to be the best place to pass the night. Dotted about amongst the trees the cheerful blaze of a dozen fires would light up the branches and foliage, making the darkness visible, and giving us a glimpse now and then of the massive walls which towered up above us...

Three-fourths of the cañon was traversed and surveyed in four days; the remaining fourth, however, presented the most formidable obstructions; for large masses of wall-rock had fallen into the narrow cleft in so many places, that no sooner had we succeeded in getting our mules and horses over one pile of debris than a fresh one lay across our path. We gradually entered, however, a more broken and open country, and gaps in the walls became proportionately frequent. Confusion seemed here to reign supreme; no longer did the abrupt walls hem us in, but large masses of rock, I may say sides of mountains, lay piled up all around. We measured one perpendicular cliff, which, from its position, was accessible to our instruments: found it to be 825 feet high, and this was below the average of the walls; so it is easy to conceive the relative magnitude of the rest. From out of this chaos the cañon gradually emerged, widening out and approaching more to the extent and appearance of a narrow valley. The south side first began to break away with sloping bluffs, covered with cactus and stunted vegetation, while the north side continued perpendicular for three miles and a half beyond the second "narrows," where it joined a huge mountain of igneous formation, consisting of six basaltic terraces one above the other, which formed a fine landmark for miles around

> to show the position of the cañon. Beyond this are foot-hills on both sides for two miles more, when the cañon merges into the widening valley, which, some six miles further on, joins that of the Río San Pedro just south of Camp Grant. In this valley nearly all of the water of the Aravaypa sinks into the earth. I hear, in fact from residents at the fort, that for many weeks during the year no surface-water whatever enters the Río San Pedro from it, although in the cañon there is always a fine stream.
>
> The result of the survey from Railroad Pass to Camp Grant is the following:

	Miles	Feet above Tide-water
Summit of Railroad Pass		4,411
Playa de los Pimas (centre of trough)	6.50	4,275
Head of Aravaypa Cañada	22.52	4,474
Eureka Spring	5.89	4.164
Head of Aravaypa Cañon	19.41	3,370
Leave high-walled cañon	14.49	2,645
Camp Grant	12.12	2,174
Total in miles	81.93	

Photographs of upper Aravaipa Creek in the period 1890-1900 (Appendix B) indicate its floodplain near Klondyke had been cleared and was under cultivation. Large cottonwoods and likely sycamore appear as a remnant gallery forest. Another photograph in the series depicts a dense, relatively young stand of cottonwood, which supported thick wild grape. Ground litter in the group was dense, far more so than can be found at present, indicating long protection from fire or flood.

Riparian forests along Aravaipa Creek in 1890-1900 were massive in size and development, and seem to have been dominated by cottonwood. Willow and sycamore also were in evidence, and more of the former appeared present than now is the case in four photographs of upper Aravaipa Creek and its canyon and dated only "before 1900" (Appendix B). Young trees attested to a successfully-reproducing community at that time, and there was no evidence for heavy grazing of the understory. Clumps of large reed, also noted by Bell (1869) (presumably Phragmites australis (Cav.) Trin.), were in the photograph near

"the chimney" on upper Aravaipa Creek. That species is a major stabilizer of riparian areas along some Arizona streams, along with with similar giant reed, Arundo donax L. (Minckley 1979a). Phragmites no longer is present along Aravaipa Creek (Appendix A).

Condition of banks in the photographs prior to 1900 appeared less incised than is seen today. Riparian trees were nearer the water's edge, and cut banks, when present, were obviously lower at that time, implying greater stability of riparian communities. There was no evidence of aquatic vegetation in any old photograph. More modern photographs of Aravaipa Canyon, other than those provided in other parts of the present report, are available in accounts by Heald (1950), Kramer (1965), van Campen (1965), and USBLM (1979).

Extensive cattle ranching was practiced in what is now southeastern Arizona from the latest 1700's through the early 1800's (Wagoner 1949, Hastings and Turner 1965). The Spanish land grants were mostly in operation south of the area, and most of these were curtailed by Apache activity in the 1840's. Following the Gadsden Purchase of 1854, occupation of the area by Americans began to expand, and ranching became a major land use (Calvin 1946). The Sierra Bonita Ranch included parts of uppermost Aravaipa Valley, and heavy grazing must have been experienced by the area during that period of time. Severe reductions in ranching again occurred in the latest 1800s, when prolonged, severe drought gripped the region (Hastings and Turner 1965) and great numbers of cattle were sold or died for lack of water and forage (Wagoner 1949). Large ranching operations were established along the immediate banks of Aravaipa Creek in the 1880s (Kramer 1965), and cattle and goats became major products (Alexander n.d.).

Mining exploration and activity commenced in the 1860s, but little production occurred until about the 1880-1890 period. Smelting operations were reported in the Klondyke area in the late 1870s (Wilson 1950, Simons 1964). Amounts of metal produced were poorly documented in the early 1900s, but about 1925 a mill was constructed at Klondyke, and yields increased (Appendix C). Lead was the principal metal produced, followed by zinc and small amounts of silver. In the period 1929-31, the Klondyke area was second in production of lead in Arizona. Operations declined in the 1930s, but in the 1940s Aravaipa claims were consolidated, mines were developed and the area became a major shipper of lead and zinc ores. One or more flotation concentrator plant(s) was built at Klondyke, which was operated until 1949. Operations ceased about 1957. Since then, limited mining has occurred, except for sand, gravel, and rock, although exploration and minor activities continue to be in evidence (USBLM 1970, 1978, and original data). A more detailed treatment of the mining industry in the Aravaipa Creek area is provided in Appendix C (see also Section V-A).

Direct use of Aravaipa Creek in early days as a water supply, for livestock at first, then for limited floodplain agriculture, and undoubtedly for mining, smelting, and concentrator operations, seemingly were compatible with maintenance of the natural biota. Riparian communities are not now as highly developed as in the late 1800's, but species composition remains almost intact. Diversions for irrigation of pasturage in wider parts of the valley and canyon have been practiced for more than 100 years (Fred Woods, pers. comm.), but are transitory enough to have had little effect on the system. Remnants of mining operations are documented as relatively high concentrations of some heavy metallic elements, as is to be outlined later, but none appears

to have had permanent detrimental effects on the biota. The general absence of application of advanced technology in the area has allowed it to be preserved.

IV. PHYSICAL ENVIRONMENT OF ARAVAIPA CREEK

A. Stream Channels

The courses of Aravaipa Creek and its tributaries are partially under structural control, but more frequently reflect antecedence of channels that have carried enough water to successfully downcut during local and regional uplifts (Section II-A). The mainstream, above the source of perennial water, follows an ancient, southeast-northwest-trending, structural valley. Much of Turkey Creek parallels (a few hundred meters west of) a gentle synclinal fold, which likely influenced its course. Spectacular antecedence is the crossing of an anticline by Aravaipa Creek near the inflow of Bear Canyon, and breaching of a major section of the Galiuro volcanics at its inner gorge (Simons 1964, Krieger 1961). The abrupt origin of water in upper Aravaipa Creek is further attributed by Simons (1964) to the channel crossing at right angles a buried fault scarp that forms an impermeable barrier to subsurface flow. Depth to water in wells on the floodplain in 1975 was 1.8 to 4.1 m immediately below the putative fault line, while those southeast (upstream) of that point had depths of water to 15.8 to more than 25 m (Gould and Wilson 1976), thus adding credence to present of some kind of barrier to underflow at that point.

Relations of gradient of the channel of Aravaipa Creek to underlying structure are generally depicted in Figure IV-1. Gradients range from less than 2.5 m/km near the source, to greater than 25 m/km within the gorge, and to about 5.0 m/km near the San Pedro River. Overall average in the flowing

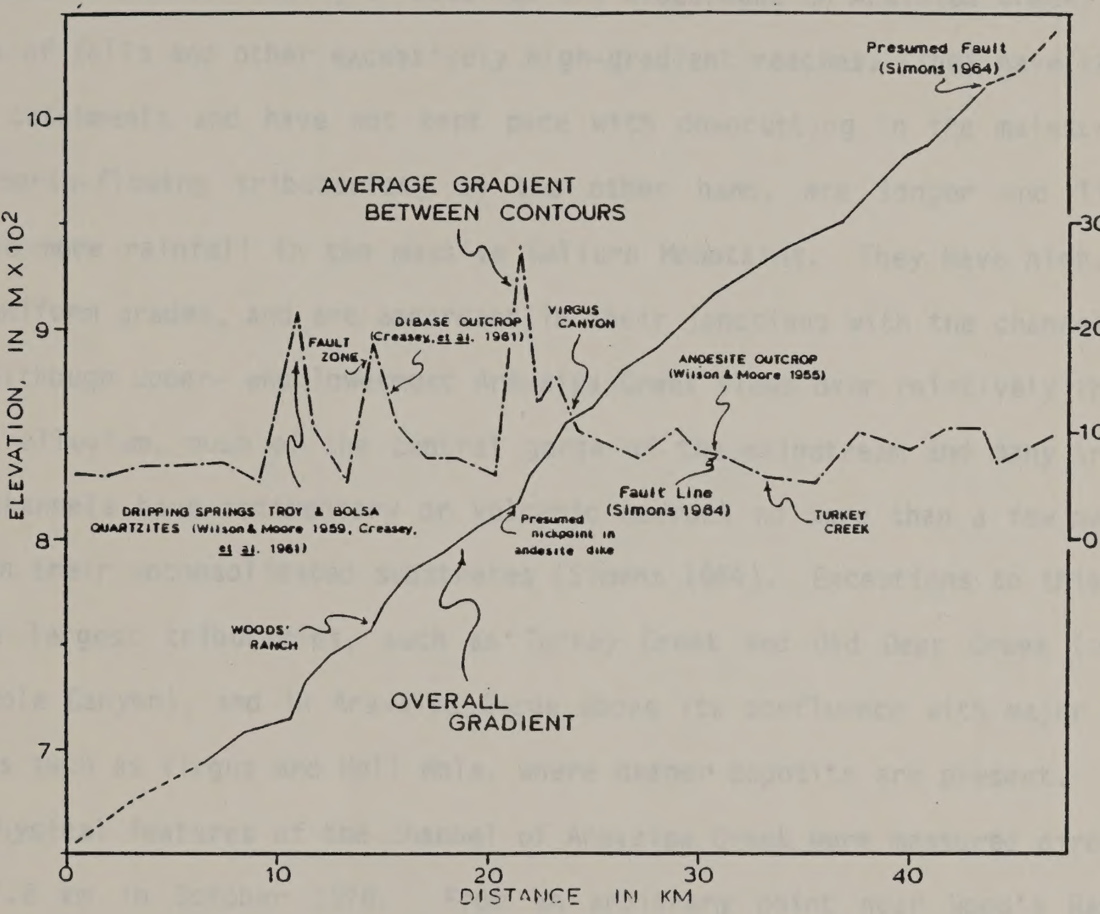


Figure IV-1. Relations of channel gradient in Aravaipa Creek, Graham and Pinal counties, Arizona, to various geologic and geographic features of the watershed. Compiled from U.S. Geological Survey Topographic Quadrangles and literature cited in the figure.

portion of channel is ca. 8.3 m/km. Average gradients between contours are low but variable above Virgus Canyon the mainstream of the Aravaipa, range from maxima of 20 to 30 m/km where the stream crosses igneous dikes within the gorge, and are again almost uniform below canyon sections (Fig. IV-1).

Some southwest-flowing tributaries are discordant to Aravaipa Creek, with series of falls and other excessively high-gradient reaches. They have rather small catchments and have not kept pace with downcutting in the mainstream. Most north-flowing tributaries, on the other hand, are longer and likely receive more rainfall in the massive Galiuro Mountains. They have high, but more uniform grades, and are accordant in their junctions with the channel.

Although upper- and lowermost Aravaipa Creek flows over relatively thick, recent alluvium, much of the central gorge of the mainstream and many tributary channels have sedimentary or volcanic bedrock no more than a few meters beneath their unconsolidated substrates (Simons 1964). Exceptions to this are in the largest tributaries, such as Turkey Creek and Old Deer Creek (upper Hell Hole Canyon), and in Aravaipa Gorge above its confluence with major side canyons such as Virgus and Hell Hole, where deeper deposits are present.

Physical features of the channel of Aravaipa Creek were measured directly over 7.8 km in October 1976. From an arbitrary point near Wood's Ranch, survey parties worked both up- and downstream, recording channel and stream widths and depths at 100-m intervals (Table IV-1). These data were used to compute mean values for the reach from the western boundary of Aravaipa Canyon Primitive Area (Fig. II-1) eastward into the canyon for 3.0 km, for another reach from that boundary for 1.7 km downstream to Wood's Ranch, and for a last segment from Wood's Ranch for 3.1 km downstream. Percentages of riffle,

Table IV-1. Statistics for physical features of 100-m segments in Aravaipa Creek, Pinal County, Arizona, October 1976; ranges in parentheses are for means of segments unless marked with asterisk, the latter are for raw data. Discharge was 0.31 m^3/s.

Parameters	Within Canyon	Above Wood's Ranch	Below Wood's Ranch
Mean channel width, m	16.6± 6.5 (4.6- 33.9)	21.9± 9.3 (10.3- 26.7)	30.2± 25.2 (9.1- 96.0)
Mean stream width, m	7.2± 2.0 (3.2- 11.4)	13.7± 3.3 (8.1- 21.5)	9.9± 3.0 (4.1- 16.0)
Mean depth, cm	10.4± 2.2 (7.3- 15.5)	7.4± 1.3 (5.7- 10.0)	7.6± 1.9 (5.1- 11.9)
Mean maximum depth, cm	61.6± 19.3 (30.0- 100.0)	39.3± 15.5 (23.0- 90.0)	34.2± 9.1 (22.0- 58.0)
Area/100-m segment, m^2	740.7± 159.3 (480.1-1028.7)	1140.3± 198.6 (777.2-1463.0)	910.5± 172.0 (685.8-1280.2)
Volume/100-m segment, m^3	76.3± 16.7 (49.1- 108.5)	84.6± 10.7 (62.1- 101.3)	68.2± 14.9 (35.9- 116.2)
Percentage pool*	11.3 (0.0- 50.0	13.2 (0.0- 45.0)	11.9 (0.0- 80.0)
Percentage riffle*	71.9 (40.0- 100.0)	82.8 (5.0- 100.0)	81.4 (20.0- 100.0)
Percentage rapid*	16.8 (0.0- 40.0)	4.6 (0.0- 50.0)	6.7 (0.0- 50.0)
Percentage single channel*	73.3 (22.4- 100.0)	52.9 (0.0- 94.5)	54.8 (0.0- 99.6)
Percentage braided channel*	26.7 (0.0- 1.5)	46.2 (0.0- 100.0)	45.2 (0.0- 100.0)
Pool/riffle-rapid ratio*	0.17 (0.0- 1.5)	0.24 (0.0- 1.5)	0.35 (0.0- 4.0)
Rapid/riffle ratio*	0.18 (0.0- 0.8)	0.09 (0.0- 0.3)	0.11 (0.0- 1.5)
Percentage shaded*	54.0 (0.0- 100.0)	55.3 (0.0- 100.0)	29.5 (0.0- 100.0)
Number of segments	30	17	31

rapid, and pool, channel configuration (braided or single), and percentage of water surface shaded during the period 0800 to 1600 hours also were noted.

Within the canyon the stream was narrower than elsewhere, was deeper on the average and at a maximum, and had less surface area and volume per 100-m segment. It typically flowed in a single channel with a large percentage of rapid habitat, and was heavily shaded. Pools were fewer but deeper than downstream (Table IV-1). The reach upstream from Wood's Ranch also was heavily shaded, but was broad and shallow with a high percentage of braided channel. This section of creek flows through a relatively broad portion of the lower canyon formed by alluvium accumulated below major side canyons and as a result of deposition above a dibase dike (Fig. IV-1). In the most downstream reach the stream passes through a complex zone of alternating canyons and broader alluviated areas. The channel becomes even wider and less complex, but stream width is somewhat less as a result of incision into valley fill. Percentage shading was substantially reduced, as was the percentage of rapid habitat.

B. Recent Alluvium

Younger alluvium of Aravaipa Creek and its tributary channels consists of unconsolidated, poorly sorted sand and gravel, plus far less cobble and boulder than in older deposits of the area. Origin and nature of flood flows have remarkable influence on sediment loads, and therefore have different impacts on the channel. Vast amounts of materials are transported to and through the system when floods originate in the upper Aravaipa Valley. Surface deposits of that relatively broad plain are fine-grained and readily carried by sheet flow or other runoff, and such an event often results in

massive aggradation downstream. Sands and gravels are temporarily deposited in wider reaches and immediately upstream from narrow places where hydraulic jumps are preceded by a decrease in competence of water to carry them (Burkham 1976a). This subjects the channel to alluviation, locally termed "sanding in," which fills pools and creates a smooth, chute- or run-like pattern of flow.

Flood waters through canyon tributaries from higher-elevation, bedrock parts of the drainage carry little suspended material, and therefore have high kinetic energy available to degrade finer sediments. Large materials are, however, moved into and through the system, after being gouged from conglomerate walls of arroyos and canyons. Alluvial fans from larger side canyons may dam Aravaipa Creek (Fig. IV-2), resulting in temporary impoundment, or if sufficiently massive and long-lasting allowing upstream development of terraces (Section IV-A). Clear-water floods of high volume degrade the channel, resulting in re-establishment of pool habitats where obstructions such as cliffs at bends accentuate scour, and riffle-run-pool conditions prevail.

Particles analyses after low-discharge years of 1974-75 show a general relationship to gradients in the various stream segments (Table IV-1, Fig. IV-3). Greatest percentage variations were in finer (< 3.2 mm) and coarser (> 12.2 mm) materials. Large particles were prevalent in reaches of steeper gradient and vice versa. Samples used were from the uppermost 5.0 cm of substrate in the center of flowing (or previously flowing) channels. Data represent percentage by weight of various particle sizes after air drying in the laboratory for periods of 5 to 18 months. Items larger than 25.4 mm were arbitrarily excluded.

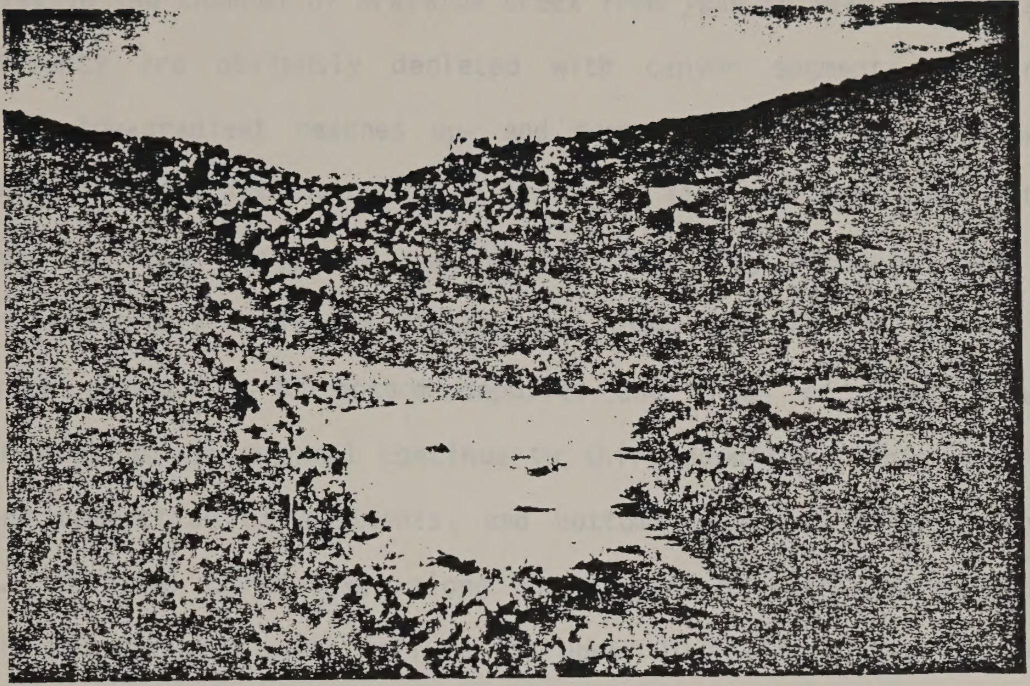


Figure IV-2. Alluvial fan resulting from flash flooding in Brandenburg Wash impounding lower Aravaipa Creek, Pinal County, Arizona, spring 1977.

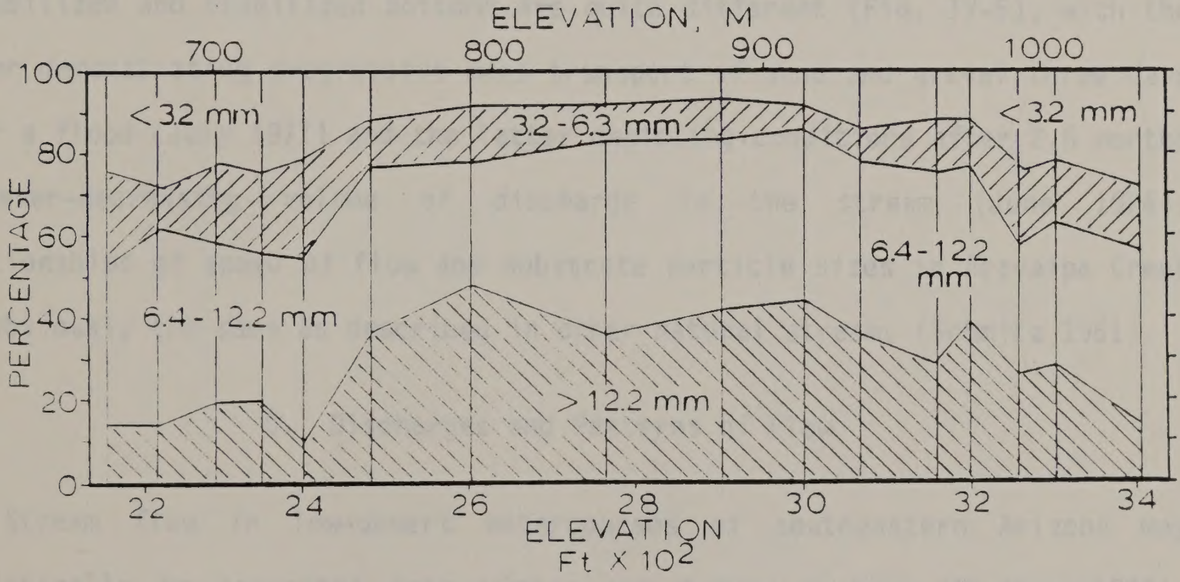


Figure IV-3. Frequency distribution of bottom particles < 25.4 mm diameter at various points on Aravaipa Creek, Graham and Pinal counties, Arizona, winter 1976. See text for further explanation.

Qualitative observations indicate similar patterns of sediment distribution persist in the channel of Aravaipa Creek from year to year. After scour, finer sediments are obviously depleted with canyon segments, but remain prevalent in low-gradient reaches up- and downstream. Periods of low discharge, or of flooding from Aravaipa Valley, move fine sediments back into the canyon, and set the stage for subsequent removal by flooding from side-canyons. Immediately following floods, and sometimes for periods of weeks after severe re-working of bottom deposits and input of finer alluvium, bottoms in much of the channel continue to shift downflow. This results in sorting and compaction of sediments, and bottoms become armored by coarser materials. Vertical cores taken along the margins of swift currents demonstrate this relationship quite well in the upper 10 to 15 cm, but the effects of sorting is less evident at deeper levels (Fig. IV-4). Relations of particle sizes at the substrate surface (upper 5.0 cm) to speed of flow over unstabilized and stabilized bottoms are quite different (Fig. IV-5), with the former demonstrating progressive mass transport of sand and gravel three days after a flood (July 1977) and the latter depicting conditions after 2.5 months of ever-decreasing volume of discharge in the stream (June 1976). Relationships of speed of flow and substrate particle sizes in Aravaipa Creek are obviously the same as described in other natural streams (Schmitz 1961).

C. Discharges and Patterns of Flow

Stream flow in low-desert watercourses of southeastern Arizona may realistically be separated into winter and summer periods (Burkham 1970). Winter flow is a result of precipitation from frontal storms, snowmelt, groundwater outflow, or a combination of the three, in the period November

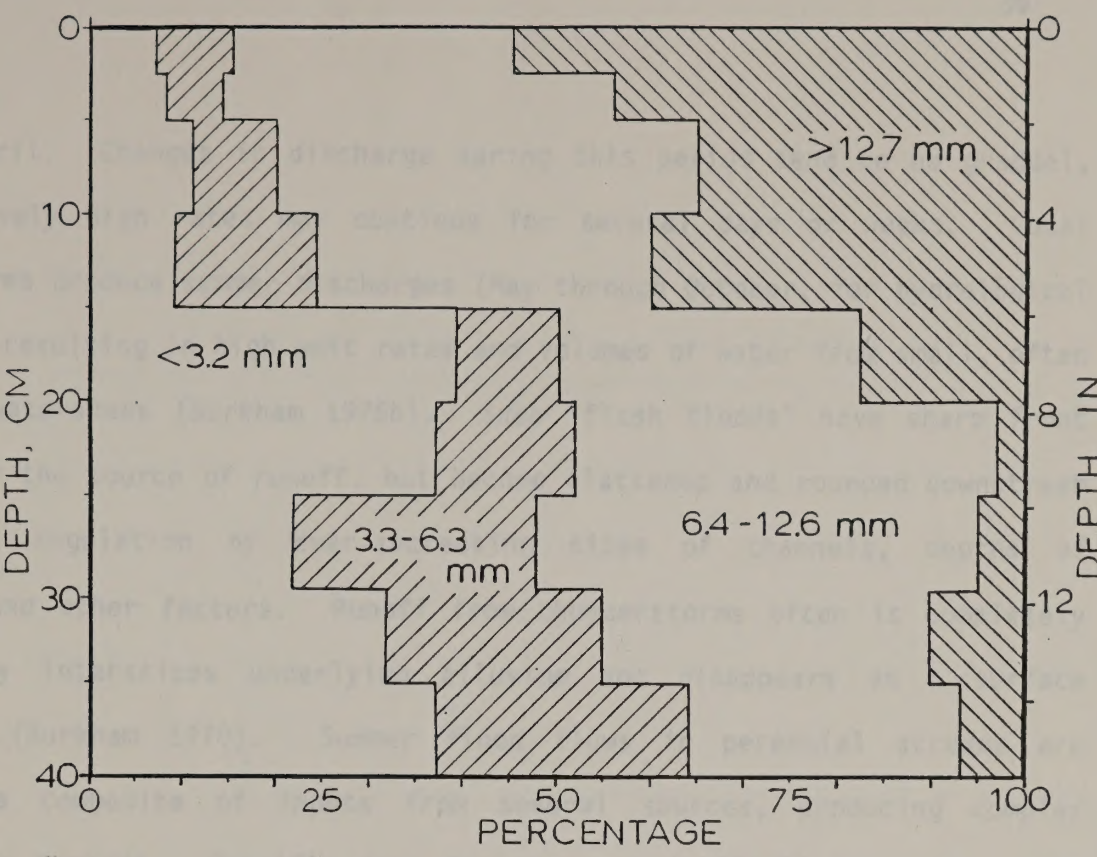


Figure IV-4. Frequency distribution of particles < 25.4 mm diameter in vertical cores adjacent to runs in Aravaipa Creek, Graham County, Arizona, winter 1976. See next for further explanation.

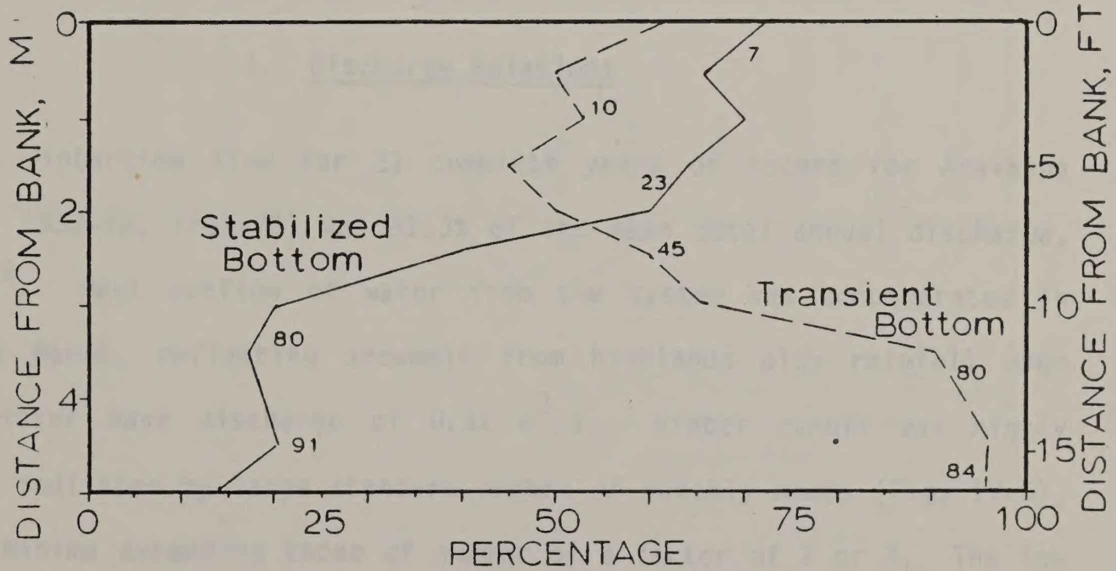


Figure IV-5. Frequency distribution of particles < 25.4 mm diameter in surficial sediments of runs of Aravaipa Creek, Graham County, Arizona, under contrasting conditions or prior discharge; numbers near curves are velocity of flow at the surface at the points of sampling. See text for further explanation.

through April. Changes in discharge during this period tend to be gradual, and relatively high rates may continue for several days or weeks. Local thunderstorms produce summer discharges (May through October, for hydrological purposes), resulting in high unit rates and volumes of water from small, often ephemeral watersheds (Burkham 1976b). Such "flash floods" have sharp front crests near the source of runoff, but become flattened and rounded downstream because of regulation by ever-increasing sizes of channels, depths of alluvium, and other factors. Runoff from thunderstorms often is completely absorbed by interstices underlying alluvium and disappears as a surface phenomenon (Burkham 1970). Summer flood flows in perennial streams are typically a composite of inputs from several sources, producing complex hydrographic records. Specific data for the period 1976-78 are to be given later with reference to biological studies (Section VI), but general patterns are discussed below.

1. Discharge Relations

Average wintertime flow for 21 complete years of record for Aravaipa Creek (1920, 1932-42, 1967-75) was 61.3% of its mean total annual discharge, or 1,550 hm^3. Most outflow of water from the system was concentrated in February and March, reflecting snowmelt from highlands plus rainfall when above the winter base discharge of 0.31 m^3/s. Winter runoff was highly variable, as indicated by large standard errors of monthly means (Fig. IV-6), with winter minima exceeding those of summer by a factor of 2 or 3. The low average and range of discharge during January most likely results from freezing conditions at higher elevations during that coldest month of the year (Green and Sellers 1964).

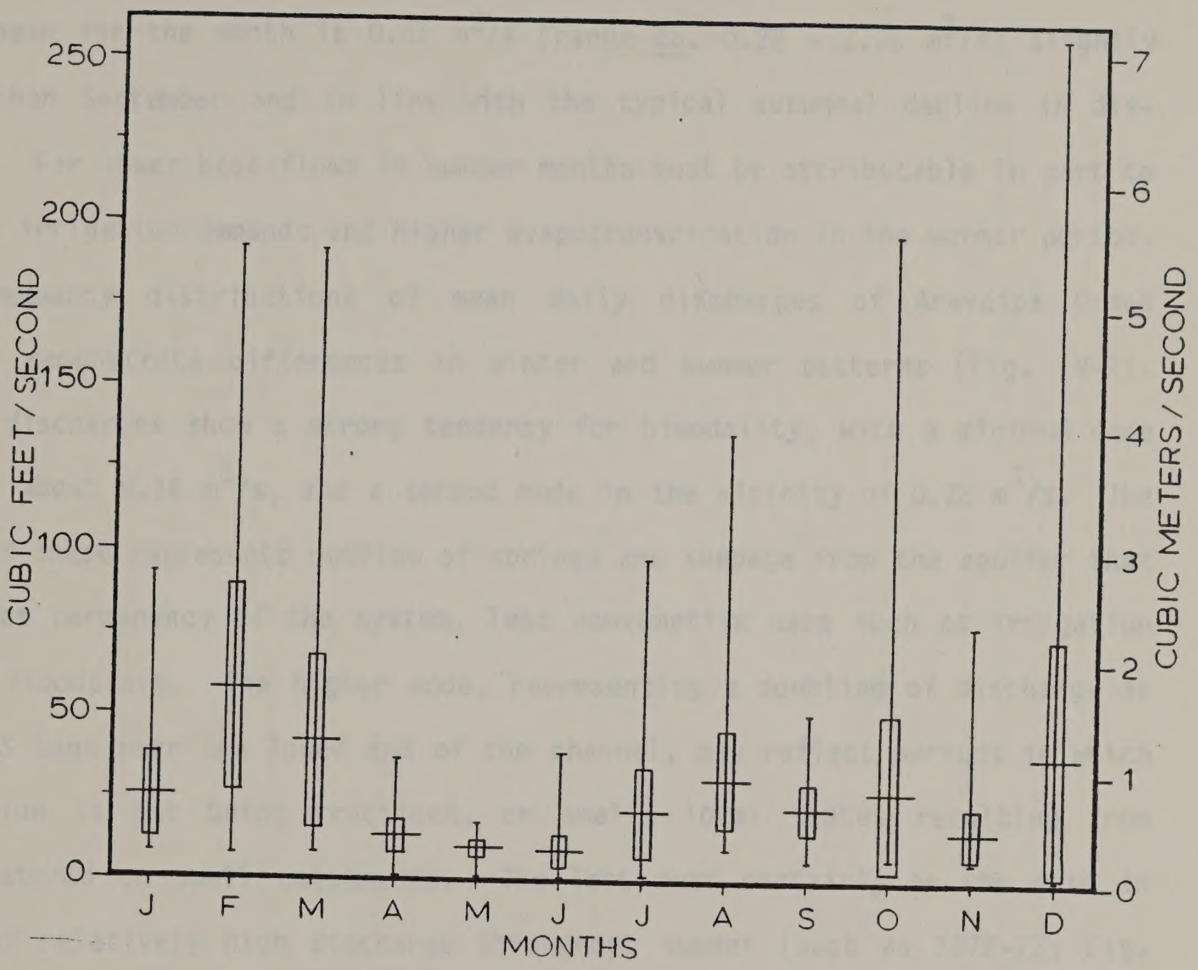


Figure IV-6. Means (horizontal lines), ranges (vertical lines), and one standard error either side of the man (rectangles) for monthly discharges in Aravaipa Creek, Pinal County, Arizona, for 21 years of record; see text for further explanation.

Summer discharges (38.7% of the total, or 980 hm^2), were lowest on the basis of mean monthly data in May and June, and highest in August in the 21 years of records (Fig. IV-6). October mean and maximum were forced upward by heavy precipitation and runoff in 1972. If that year is excluded from the data, mean for the month is 0.61 m^3/s (range *ca.* 0.22 - 2.26 m^3/s) slightly lower than September and in line with the typical autumnal decline in discharge. Far lower base flows in summer months must be attributable in part to greater irrigation demands and higher evapotranspiration in the warmer period.

Frequency distributions of mean daily discharges of Aravaipa Creek further demonstrate differences in winter and summer patterns (Fig. IV-7). Summer discharges show a strong tendency for bimodality, with a minimum base flow of about 0.14 m^3/s, and a second mode in the vicinity of 0.28 m^3/s. The first of these represents outflow of springs and seepage from the aguifer that maintains permanency of the system, less consumptive uses such as irrigation on the floodplain. The higher mode, representing a doubling of discharge at the USGS Gage near the lower end of the channel, may reflect periods in which irrigation is not being practiced, or small, local spates resulting from thunderstorms on small catchments. The last must certainly be the case in years of relatively high discharge throughout summer (such as 1972-73; Fig. IV-7), where the bimodal pattern persists. Winter discharges tend to be unimodal and far less variable than those in summer.

Highly permeable substrates in southwestern streams may transport a large percentage of the overall discharge of a system as sub-surface flow. Surface discharge also may vary up- to downstream, with reaches of dry channel alternating with segments of strong epigean flow (Heindl and McCullough 1961). At high discharges, alluvium becomes saturated, and variations up- to downstream

Summer discharges (29.7% of the total, or 380 hm^3), were lowest on the basis of mean monthly data in May and June, and highest in August in the 33 years of records (Fig. IV-6). October mean and maximum were forced upward by heavy precipitation and runoff in 1972. If that year is excluded from the data, mean for the month is 0.91 m^3/s (range ca. 0.22 - 2.26 m^3/s) slightly lower than September and in line with the typical autumnal decline in discharge. Far lower base flows in summer months must be attributable in part to greater irrigation demands and higher evapotranspiration in the warmer period.

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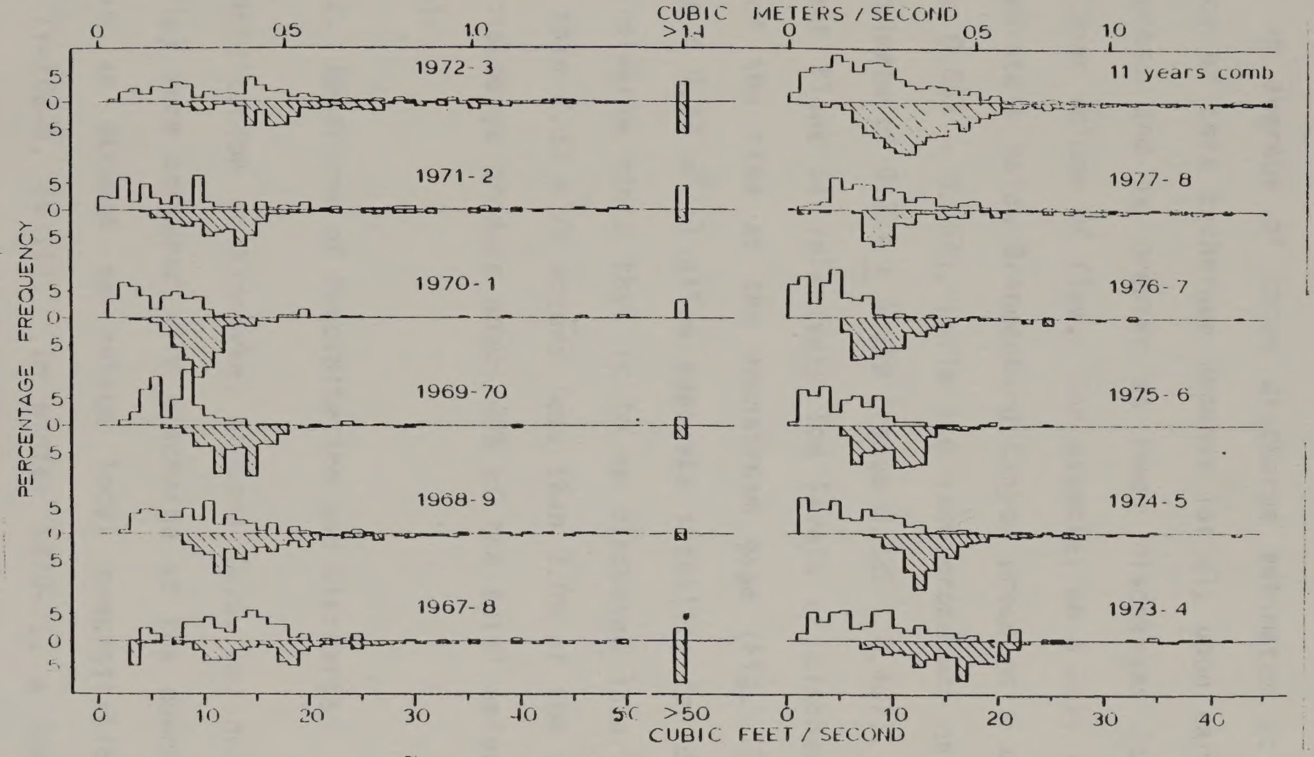

Figure IV-7. Frequency distributions of mean daily discharges in summer (above) and winter (below and hatched) in Aravaipa Creek, Pinal County, Arizona, water-years 1967 - 1977; compiled from U.S. Geological Survey records.

consist of progressive increases as inflow accumulates from Springs and tributaries. These phenomena are illustrated for Aravaipa Creek in Figure IV-8a-b. Data were collected by the Embody (1927) cork-float method, and points represent an average of three discharge estimates at each sampling station. Accuracy of this technique depends largely upon care taken in the various measurements, and is greater at lower discharges (smaller channel sizes) than at higher volume of flow. For example, on 6 July 1977, estimates of discharge immediately below Brandenburg Canyon produced a mean of 0.055 ± 0.002 m^3/s (range 0.053 - 0.057), while the same procedure on 28 March 1977 resulted in an estimate of 0.374 ± 0.039 (range 0.332 - 0.407).

Aravaipa Creek flows at relatively low levels of discharge, less than 0.57 m^3/s, 90% of the time at the downstream gage (Fig. IV-9), and such volumes (>0.0 and < 0.57 m^3/s) allow adequate stability for development and maintenance of a diverse biota that is to be discussed later. Destructive flooding of more than 2.83 m^3/s occurs less than 3.0% of the time. Each of these levels of discharge produce about 40% of the total water yield of the system (Fig. IV-9).

2. Relations of Precipitation and Discharge

Data for precipitation at Klondyke, Arizona (U.S. Weather Bureau, published periodically) were compared with discharge at the downstream gage on Aravaipa Creek in an attempt to relate local precipitation and stream discharge (Figs. IV-10a-b, IV-11). In winter 1970-71, a low-flow period, discharge variations in periods of no recorded rainfall at the Klondyke station were almost as great as when precipitation of near 2.0 cm was recorded in a single day (Fig. IV-10a). By contrast, the hydrograph for a wetter

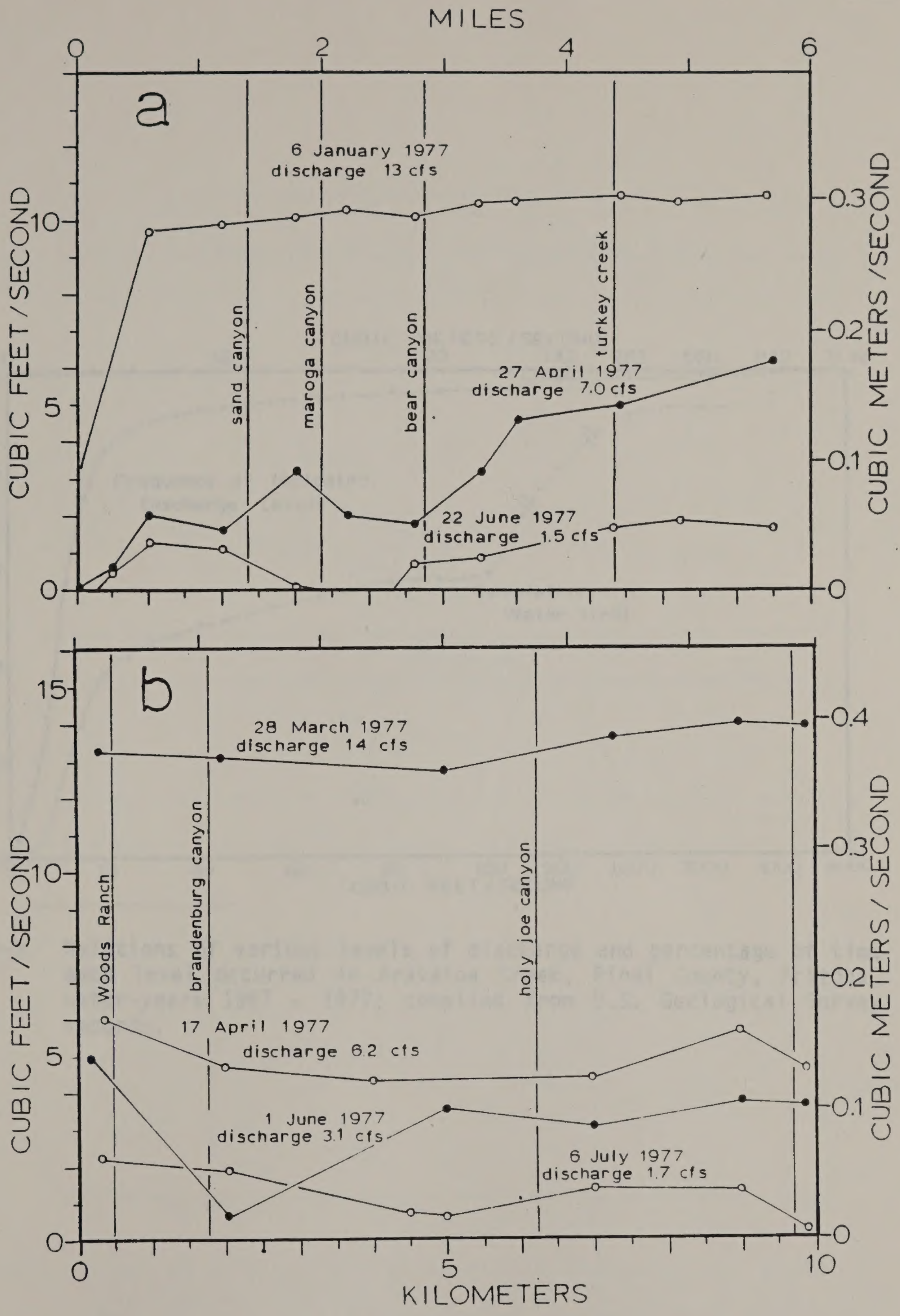

Figure IV-8. Instantaneous discharge estimates up- to downstream in upper (a) and lower (b) Aravaipa Creek, Graham and Pinal counties, Arizona; see text for further explanation.

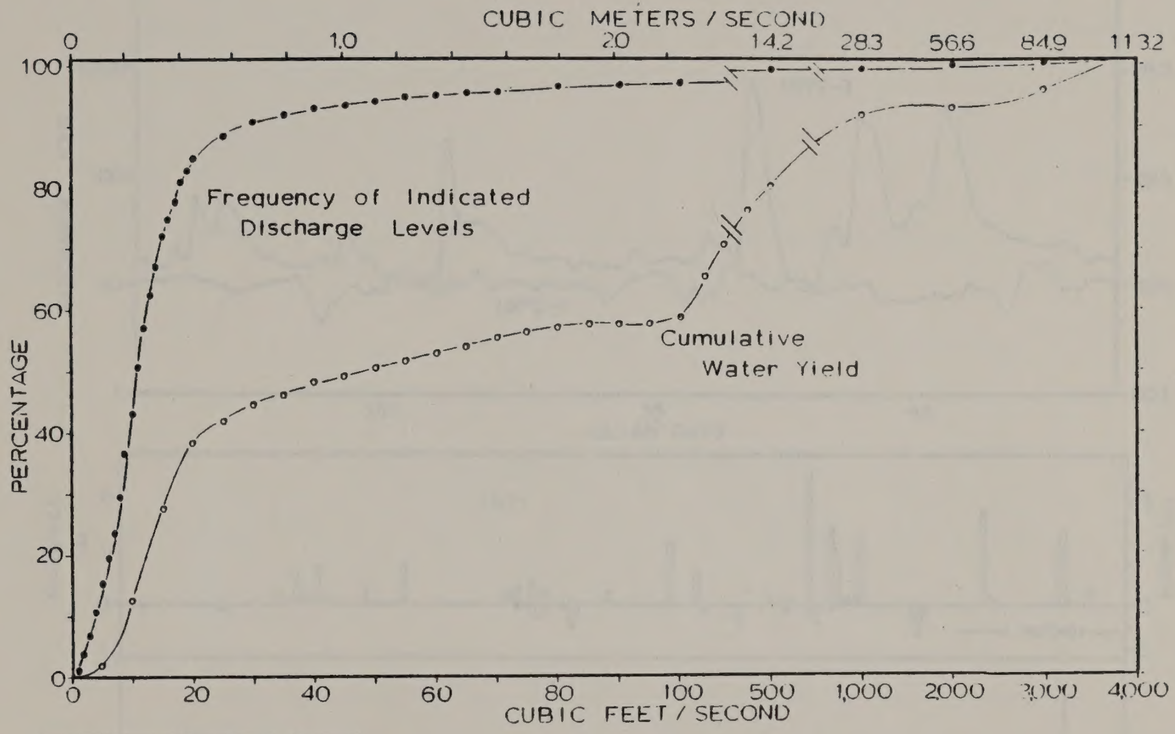

Figure IV-9. Relations of various levels of discharge and percentage of time each level occurred in Aravaipa Creek, Pinal County, Arizona, water-years 1967 - 1977; compiled from U.S. Geological Survey records.

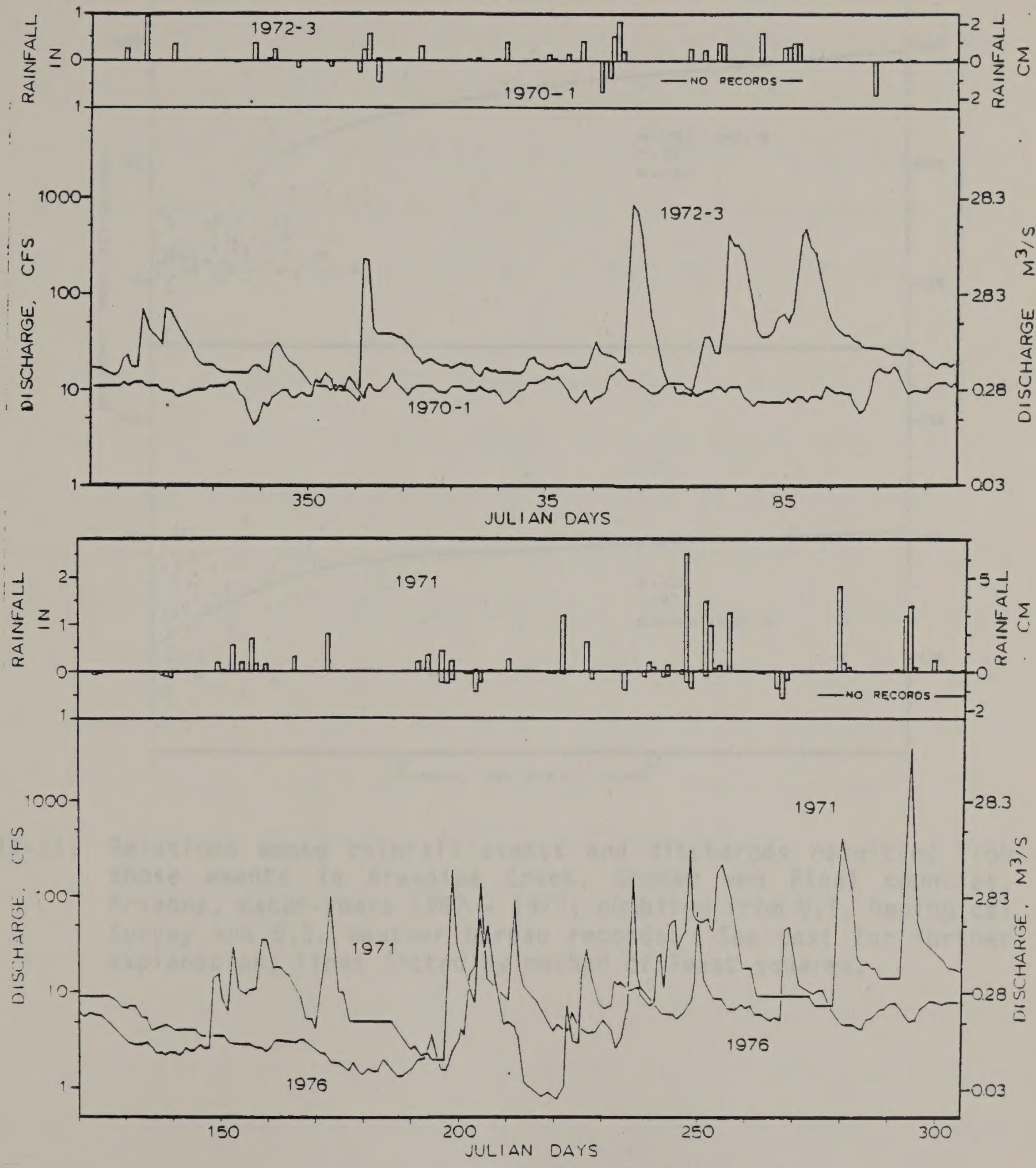

Figure IV-10. Relations of precipitation events and winter (a) and summer (b) discharges of Aravaipa Creek, Graham and Pinal counties, Arizona, in high and low discharge periods (upper and lower, respectively, in a and b).

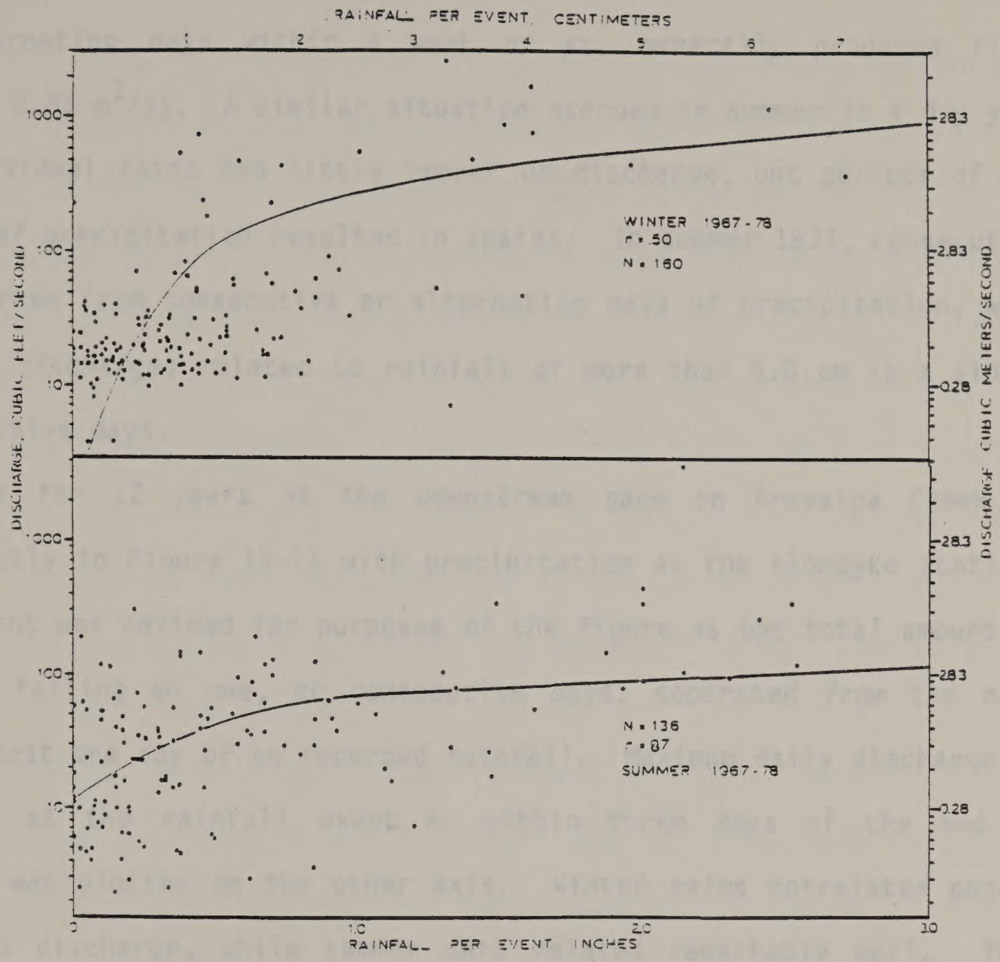

Figure IV-11. Relations among rainfall events and discharges resulting from those events in Aravaipa Creek, Graham and Pinal counties, Arizona, water-years 1967 - 1977; compiled from U.S. Geological Survey and U.S. Weather Bureau records. See text for further explanation; lines fitted by method of least squares.

winter (1972-73) demonstrated definite responses of the stream to precipitation. Rainfall of relatively long duration, over two or more consecutive days on alternating days within a week or so, generally produced flood conditions (> 2.83 m^3/s). A similar situation accrued in summer in a dry year (1976). Individual rains had little impact on discharge, but periods of two or more days of precipitation resulted in spates. In summer 1971, consecutive flooding occurred from consecutive or alternating days of precipitation, with highest daily discharges related to rainfall of more than 5.0 cm in a single or two consecutive days.

Discharge for 12 years at the downstream gage on Aravaipa Creek is compared directly in Figure IV-11 with precipitation at the Klondyke station. A rainfall event was defined for purposes of the figure as the total amount of precipitation falling on one, or consecutive days, separated from the next event by at least one day of no recorded rainfall. Maximum daily discharge on the same day as the rainfall event or within three days of the end of precipitation was plotted on the other axis. Winter rains correlated poorly with increased discharge, while summer data related remarkably well. This contrasts with findings of Burkham (1970), who demonstrated a far higher correlation of winter rains and runoff than was present in summer in the Gila River, eastern Arizona.

On an overall basis, average water yield of 1.79 hm/km^2/year from the Aravaipa Creek watershed is remarkably similar to that of the larger Gila - San Francisco rivers basin of eastern Arizona (1.81 hm/km^2/year; Minckley 1979b). Assuming an average precipitation of ca. 32 cm/year over the drainage, the mean discharge of 2,530 hm/year in Aravaipa Creek represents about 5.5% of the available water falling on the region.

D. Water Temperatures

Temperatures in streams are subject to substantial changes on an annual and daily basis. Annual variations tend to follow those of local, terrestrial climates, while diurnal changes are superimposed upon the broader pattern through effects of heating by absorption of solar energy and cooling mostly through evaporation (Hynes 1970). Mixing in turbulent channels effects essential homeothermy in a given reach, with stratification in deep, protected pools (Neel 1951) being an exceptional circumstance. Volume of discharge has a large impact on thermal conditions in streams, since larger amounts of water obviously require far more energy for heating or cooling than smaller ones. Other factors influencing rates and magnitudes of change are shading, relative volumes of surface vs. subsurface water, air movement (wind), and relative humidities (Macan 1958, Kamler 1965).

Annual means for water temperatures in Aravaipa Creek, computed as the average of maximum and minimum daily temperature as recommended by Macan (1958), tended to be higher than mean air temperature of the region in autumn, winter, and spring, and lower than air temperature in summer (compare Fig. IV-12 with Fig. II-2 and Table II-1). Water in upper Aravaipa Creek remained cooler in summer and warmer in other seasons than that in the lower reach, presumably because of greater volumes of underflow near the headwaters, plus inflow of seeps and springs in that area.

Temperature variations in the stream were far greater than has been elsewhere reported (Figs. IV-12 - IV-13). Hynes (1970) considered diurnal variation of 6.0° C in summer as near a maximum in small streams, yet Aravaipa Creek had diurnal variation that averaged more than that value in most seasons, and maximum daily variation of 12.5° C in summer and 11.5° C winter

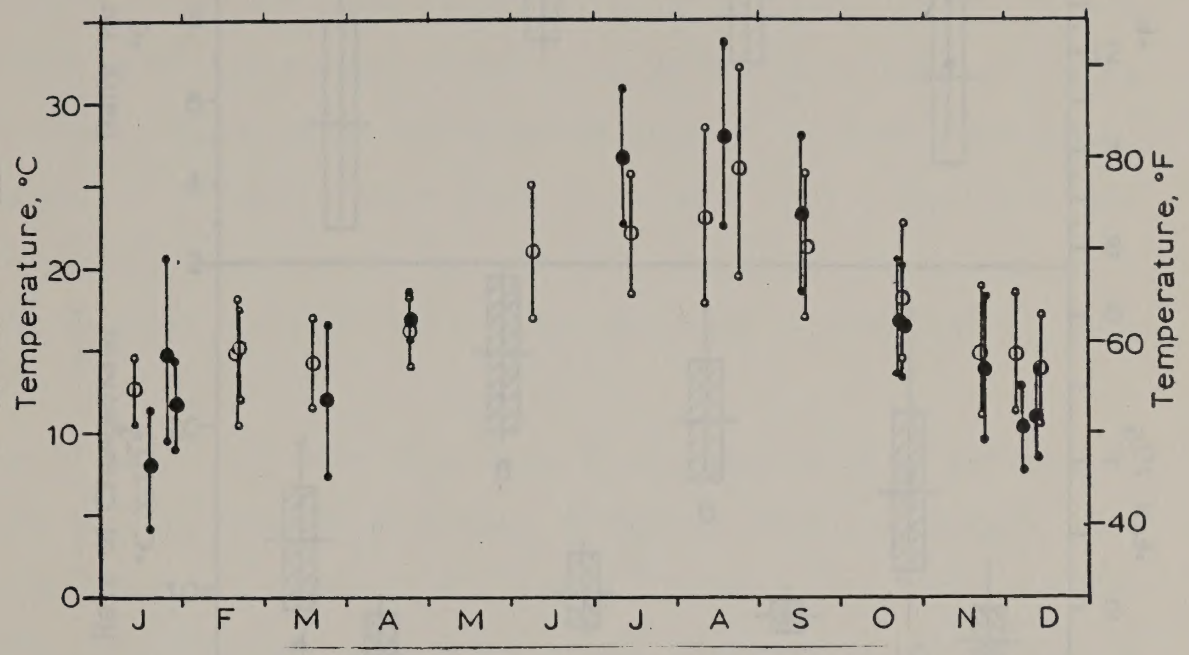

Figure IV-12. Ranges and means of water temperatures in Aravaipa Creek, Graham (= upper Aravaipa, open circles) and Pinal (= lower Aravaipa, dots) counties, Arizona, 1976 - 1978; means are of maximum and minimum daily values, following Macan (1958). See text for further discussion.

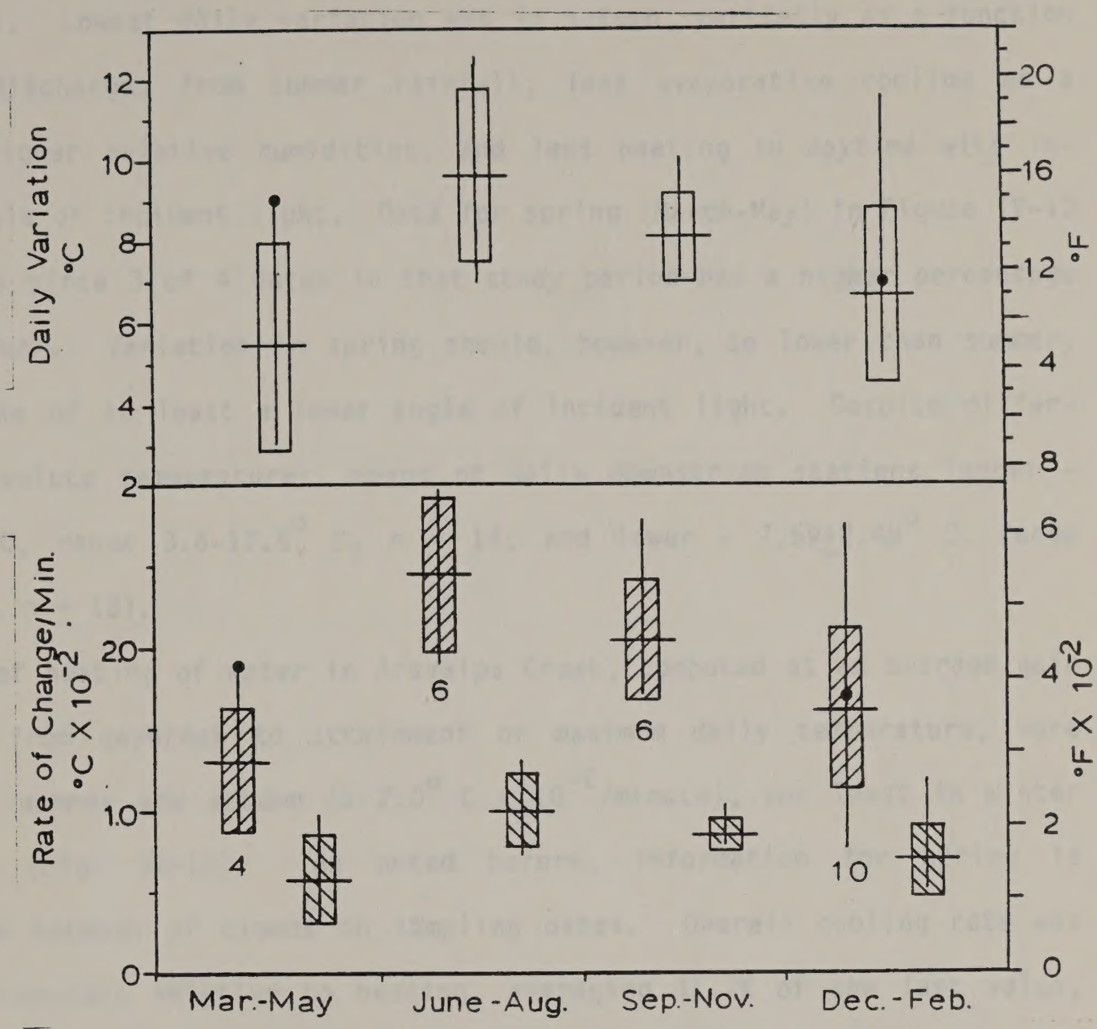

Figure IV-13. Means (horizontal bar), ranges (vertical lines), and one standard error either side of the means (rectangle) for daily variation (upper) and rates of change (lower) in water temperatures in Aravaipa Creek, Graham and Pinal counties, Arizona. Dots are mean temperatures or rates of change excluding data for cloudy days; see text for further explanation.

(Fig. IV-13). Lowest daily variation was in autumn, partially as a function of higher discharges from summer rainfall, less evaporative cooling as a result of higher relative humidities, and less heating in daytime with increasing angle of incident light. Data for spring (March-May) in Figure IV-13 are spurious since 3 of 4 dates in that study period had a higher percentage of cloud cover. Variation in spring should, however, be lower than summer, again because of at least a lower angle of incident light. Despite differences in absolute temperatures, means of daily downstream stations (upper - $7.35 \pm 2.29^{\circ}$ C, range 3.6-12.5° C, n = 14; and lower - $7.59 \pm 2.49^{\circ}$ C, range 3.1-11.5° C, n = 13).

Rates of heating of water in Aravaipa Creek, computed as an average gain per minute from daybreak to attainment of maximum daily temperature, were greatest in summer and autumn ($> 2.0^{\circ}$ C x 10^{-2}/minute), and least in winter and spring (Fig. IV-13). As noted before, information for spring is questionable because of clouds on sampling dates. Overall cooling rate was remarkably constant relative to heating, averaging 41.7% of the last value, with a standard error of only 3.6% (range 37 to 52).

Daily heating began abruptly as sunlight impinged upon the water, at daybreak in open areas or somewhat later when stations were just downstream from canyon-shaded sections (see data for 770820 in Fig. IV-14), or where riparian vegetation shaded the water. Heavily shaded segments of the stream, as within Aravaipa Canyon, were significantly cooler at mid-day than other reaches (Table IV-2).

Maximum temperatures at most points in the creek were attained between 1400 and 1600 hours, then cooling ensued until minima were achieved just before daybreak. Cooling of the stream from its daily maximum to minimum was

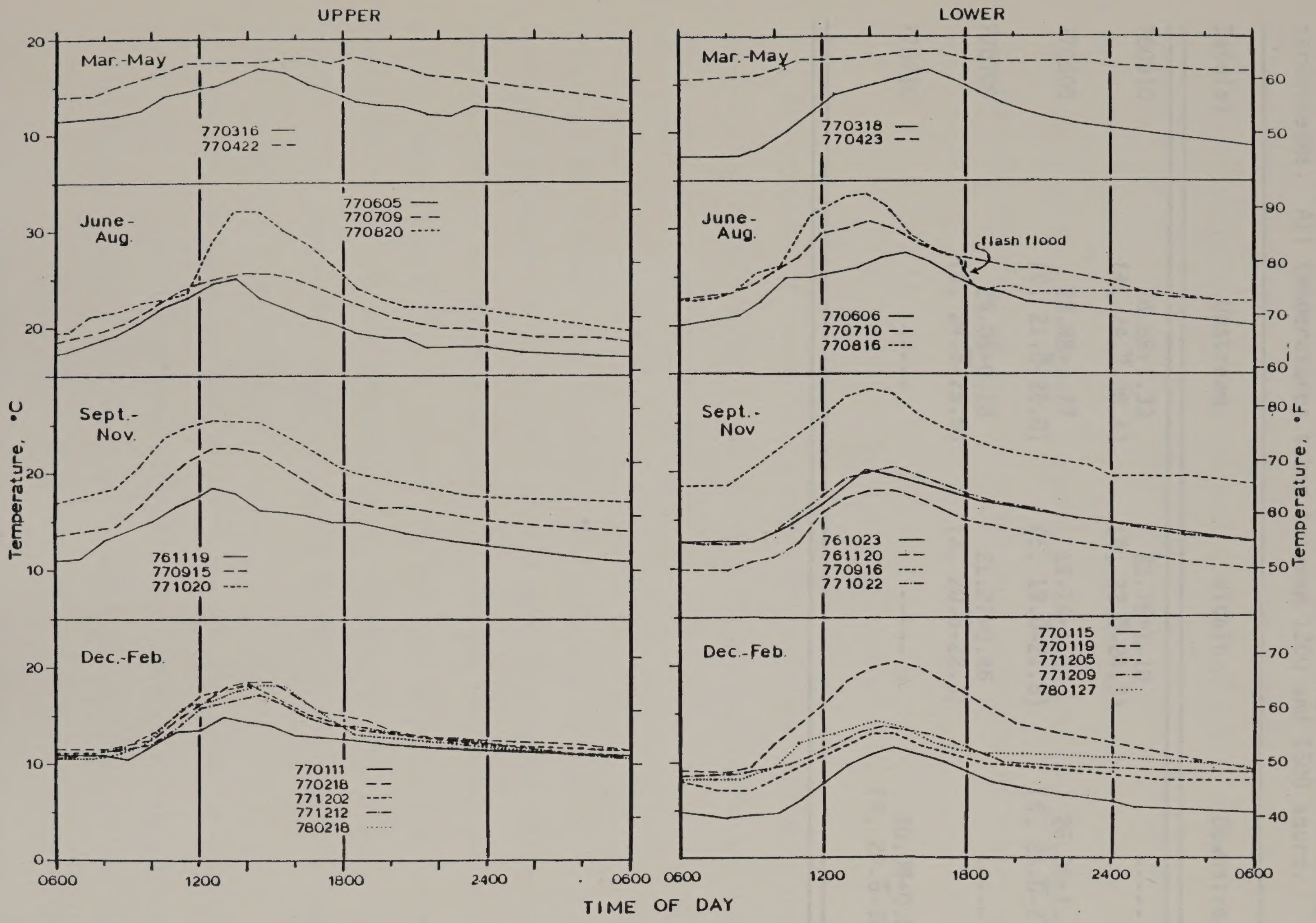

Figure IV-14. Diurnal variation in water temperatures in Aravaipa Creek, Graham and Pinal counties, Arizona. Raw data from which these semi-diagramatic curves were plotted are in Appendix D (Tables A-B).

Table IV-2. Water temperatures above, within, and below Aravaipa Canyon, Graham and Pinal counties, Arizona; numbers of samples followed by ranges in parentheses. All temperatures taken between 1200 and 1500 hours.

Date(s)	Upstream	Within	Downstream
760910	26.68±1.33 (4, 24.3-28.4)	22.75±1.10 (4, 22.0-24.3)	-----
770605	22.88±1.77 (8, 21.0-25.0)	19.74±1.14 (5, 19.0-21.5)	26.00±1.10 (6, 25.0-27.5)
770709	25.05±0.18 (4, 24.5-25.5)	21.27±0.86 (3, 20.5-22.3)	-----
770710	-----	-----	30.08±0.29 (4, 29.5-32.0)

initially rapid, reflecting low relative humidities in late afternoon, then slowed after darkness. Highest temperatures occurred when relative humidity was high and accompanied by intense insolation after summer rains (July-August; Figs. IV-13, IV-14). Cloud cover effectively limited heating in the stream (all but 770318 in the March-May period in Fig. IV-14 had extensive or complete cloudiness), producing the least variation recorded on a daily basis. Raw data on temperatures of the stream are reproduced in Appendix D (Tables A-B).

E. Turbidity and Light

Measurements of turbidity in waters of Aravaipa Creek were less than 1.0 Jackson Turbidity Unit (JTU) when discharges were lower than 1.0 m^3/second and had been so for a period of more than 10 days. Flow exceeding 2.83 m^3/second invariably carried large amounts of suspended matter, but there was little relationship between JTU estimates and the actual weights of sediments in samples from floods (Fig. IV-15). Coarse particles sedimented so quickly from samples that no reliable measurements of JTU was obtained. Weights of particulate materials per unit volume further correlated only generally with discharge (Fig. IV-16), indicating as demonstrated by Fisher and Minckley (1978) that suspended load is highly variable in time and space during flooding in desert watercourses.

Samples allowed to settle for 3 to 5 days after collection retained turbidity in the form of semi-colloids and colloids. In 11 samples from floodwaters in summer, JTU readings ranged from 14 to 56. Eight samples from winter floods all had greater than 100 JTU after 3 to 5 days without agitation. These differences must reflect differing origins of water. As noted in

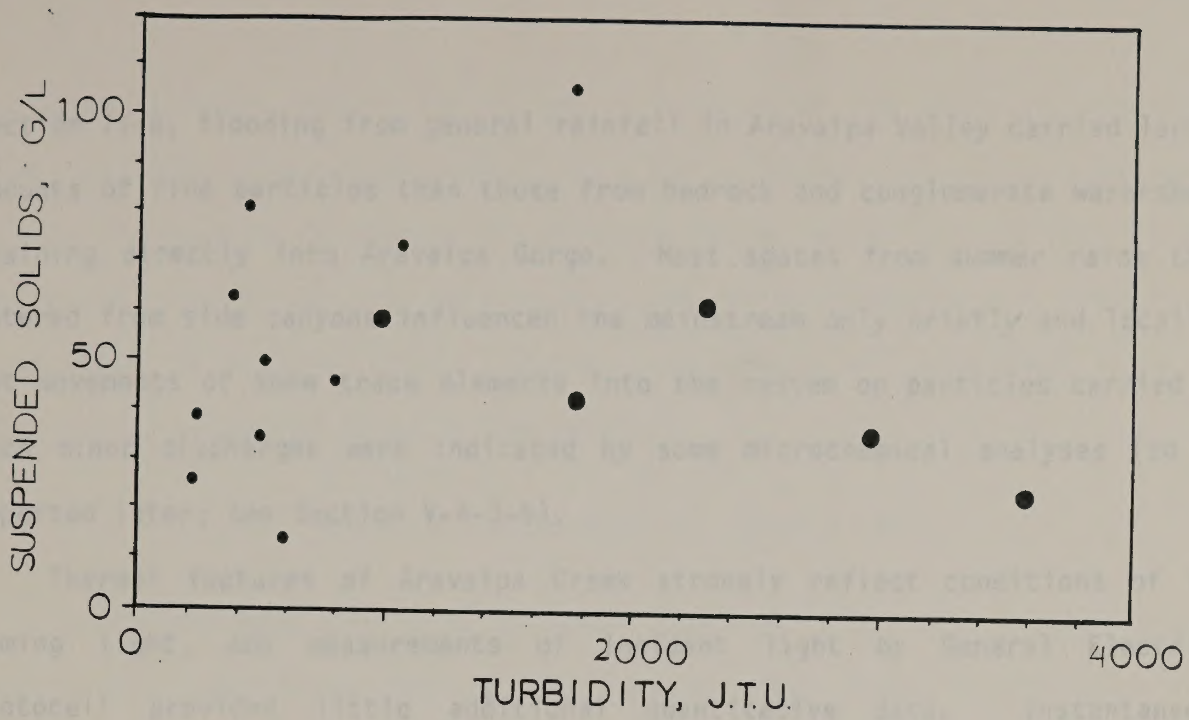

Figure IV-15. Relationship between turbidity as measured in Jackson Turbidity Units (J.T.U.) and gravimetric measurement of suspended solids, Aravaipa Creek, Arizona.

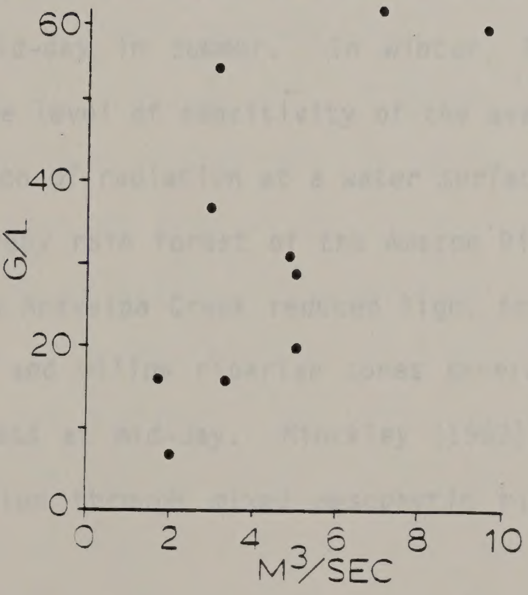

Figure IV-16. Relationship between discharge and gravimetric measurement of suspended solids, Aravaipa Creek, Arizona.

Section IV-B, flooding from general rainfall in Aravaipa Valley carried larger amounts of fine particles than those from bedrock and conglomerate watersheds draining directly into Aravaipa Gorge. Most spates from summer rains that entered from side canyons influenced the mainstream only briefly and locally, but movements of some trace elements into the system on particles carried by such minor discharges were indicated by some microchemical analyses (to be reported later; see Section V-A-3-b).

Thermal features of Aravaipa Creek strongly reflect conditions of incoming light, and measurements of incident light by General Electric^R photocell provided little additional quantitative data. Instantaneous measurements of intensity of shading produced by cliffs and riparian vegetation were, however, instructive. North-facing cliffs completely shaded the stream, reducing light at the water surface to less than 5.0% of that present in open areas at mid-day in summer. In winter, light intensities in such places were below the level of sensitivity of the available instrument.

Similar reduction of radiation at a water surface was reported by Fittkau (1964) in closed-canopy rain forest of the Amazon River basin, but only dense sycamore trees along Aravaipa Creek reduced light to less than 20% when fully leafed. Cottonwood and willow riparian zones generally allowed 30 to 50% of incident light to pass at mid-day. Minckley (1963) similarly reported about 50% light transmission through mixed mesophytic riparian forests along Doe Run, Kentucky.

Penetration of light to the bottom in Aravaipa Creek was 90% or greater of incident light at the water surface for all measurements recorded at mid-day in summer when the stream was clear. In late evening and early morning, 40 to 60% of incident light reached the substrate. Turbulence (roughening of

the water surface) reduces reflection of sunlight at low angles of incidence (Dimhirn 1953), thus accounting in part for relatively high levels of penetration. The high percentage of diffused radiation within confines of the canyon and riparian gallery forests also undoubtedly accounts for substantial penetration of visible light. Winter measurements of subsurface light at mid-day also resembled those at the surface.

V. CHEMICAL ENVIRONMENT OF ARAVAIPA CREEK

Little has been published on water chemistry of streams in the Sonoran Desert, and essentially nothing has appeared that deals specifically with Aravaipa Creek. An early report by Heindl (1952) included analyses of a single sample with specific conductance of 438 umhos/cm (at 25° C), total dissolved solids (TDS) — 787 mg/l, total hardness — 168 mg/l, bicarbonate (HCO_3^-) alkalinity — 253 mg/l, sulfate (SO_4^{--}) — 17 mg/l, chloride (Cl^-) — 8 mg/l, and flouride (F^-) — 1.2 mg/l. Minckley (1972) reported on several macrochemical conditions of the stream, including a range in pH from 7.0 to 8.5 depending upon site and time of day. Dissolved oxygen (DO) and oxygen saturation also varied noticeably with time, with the latter ranging from 50% to 150%. (The low value was achieved at night and suggested substantial respiration within the system.) Nutrients, nitrate-nitrogen (NO_3-N) and phosphate-phosphorus (PO_4-P) decreased from up- to downstream in the channel. The former ranged from 0.08 to 0.26 mg/l and the latter from 0.02 to 0.17 mg/l. Sommerfeld (1977) produced data and reported upon microchemical constituents of the stream and some of its tributaries, and his information is presented as the following section.

A. Microchemical Studies

by Milton R. Sommerfeld

1. Introductory Remarks

Most trace (microchemical) elements are essential to organisms in minute quantities. Few thus far have had no demonstrable biological function. At elevated concentrations, however, many are acutely or chronically toxic, and in areas such as the Aravaipa Creek watershed, old mines and mine workings are a potential source of substantial quantities of such materials.

Major difficulties arise in assessment of effects of specific concentrations of an element on a given organism. Most animals ingest both dissolved and suspended materials from surface waters as they drink. Humans tend to avoid suspended particulate matter and high levels of some dissolved materials. Aquatic animals ingest both dissolved and particulate fractions. Aquatic plants, on the other hand, absorb only dissolved forms. Different species, ages, and life-cycle phases may furthermore have different tolerances for various elements. Other complicating factors are chemicals such as calcium (Ca^{++}) and magnesium (Mg^{++}) ions, organic load, oxidation state of the element question, and other associated trace elements, which may act synergistically or antagonistically (McKee and Wolf 1963).

In an attempt to deal with toxic effects of dissolved substance in water, state and federal standards have been adopted for municipal and other water supplies. Standards for other surface waters are not so well defined. The Federal Water Pollution Control Administration (USFWPCA 1968) recommended that standards for certain elements be some fraction of a lethal dose based upon bioassays using "sensitive" freshwater species. More recently the Environmental Protection Agency (USEPA 1976) established water quality criteria

that "specify concentrations of constituents that, if not exceeded, are expected to support an aquatic ecosystem suitable for higher uses of water."

2. Methods

Water samples for microchemical analyses were collected at several elevations on Aravaipa Creek and in various tributaries (Turkey Creek, Bear, Hell's Half Acre, Hell Hole, Paisano, Horse Camp, and Virgus canyons, and an unnamed canyon; Tables V-1 - V-2, Fig. V-1). Duplicate samples were obtained where surface water was available on the following dates: 9-11 August, 23-24 October, 19-21 November 1976; and 21-22 January 1977. Those for analysis of dissolved constituents were filtered through acid-washed (1.0% hydrochloric acid [HCl]) membrane filters (0.45-um pore size) using 50-ml polypropylene syringes and 47-mm, plastic filter holders. Several hundred milliliters of sample was filtered and placed in acid-washed polypropylene bottles. Filtered samples were acidified in the field with 2.0 ml/l of ultra-pure Ultrex nitric acid. The duplicate sample was not filtered, but was acidified (HCl) as previously noted for total of acid-extractable element determinations.

Sample preparation for total elements involved further laboratory acidification with 2.5 ml/100 ml of ultra-pure, concentrated HCl and heating for 15 minutes. After cooling, the sample was filtered as described above and brought back to 100-ml volume with de-ionized, glass-distilled water.

All containers were washed 3 times in 1.0% HCl followed by 3 rinses in de-ionized, glass-distilled water. Analyses were performed by atomic absorption techniques using a Perkin-Elmer Model 403 spectrophotometer. Major cations, calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}), and potassium (K^{+}),

Table V-1. Sampling sites on Aravaipa Creek, Arizona (See also Fig. V-1).

Site No.	Elevation (m)	Description
1	1006.8	Below Source
2	983.0	1.5 mi. below source
3	975.4	At Maroga Canyon
4	960.1	Below Maroga Canyon
5	935.7	Below Turkey Creek
6	906.8	Below Hell Hole Canyon
7	872.6	0.5 mi. below Booger Canyon (Between Horse Camp and Booger)
8	859.5	At Horse Camp Canyon
9	851.9	Below Virgus Canyon
10	816.9	At Hell's Half Acre Canyon
11	792.5	At Wagner Ranch
12	791.0	At Wood's Ranch
13	755.9	At J. White Ranch
14	707.1	Below J. White Ranch
15	658.4	At Highway 77

Table V-2. Sampling sites on tributaries of Aravaipa Creek, Arizona (See also Fig. V-1); samples 50-100 m upstream from mouth unless otherwise indicated.

Site No.	Elevation (m)	Description
T1	976.9	Turkey Creek, Midway
T2	961.6	Bear Canyon
T3	937.3	Turkey Creek (at mouth)
T4	914.4	Hell Hole Canyon
T5	899.2	Paisano Canyon (400 m upstream)
T6	883.9	Horse Camp Canyon
T7	868.7	Virgus Canyon
T8	829.1	Hell's Half Acre Canyon
T9	701.0	Unnamed tributary

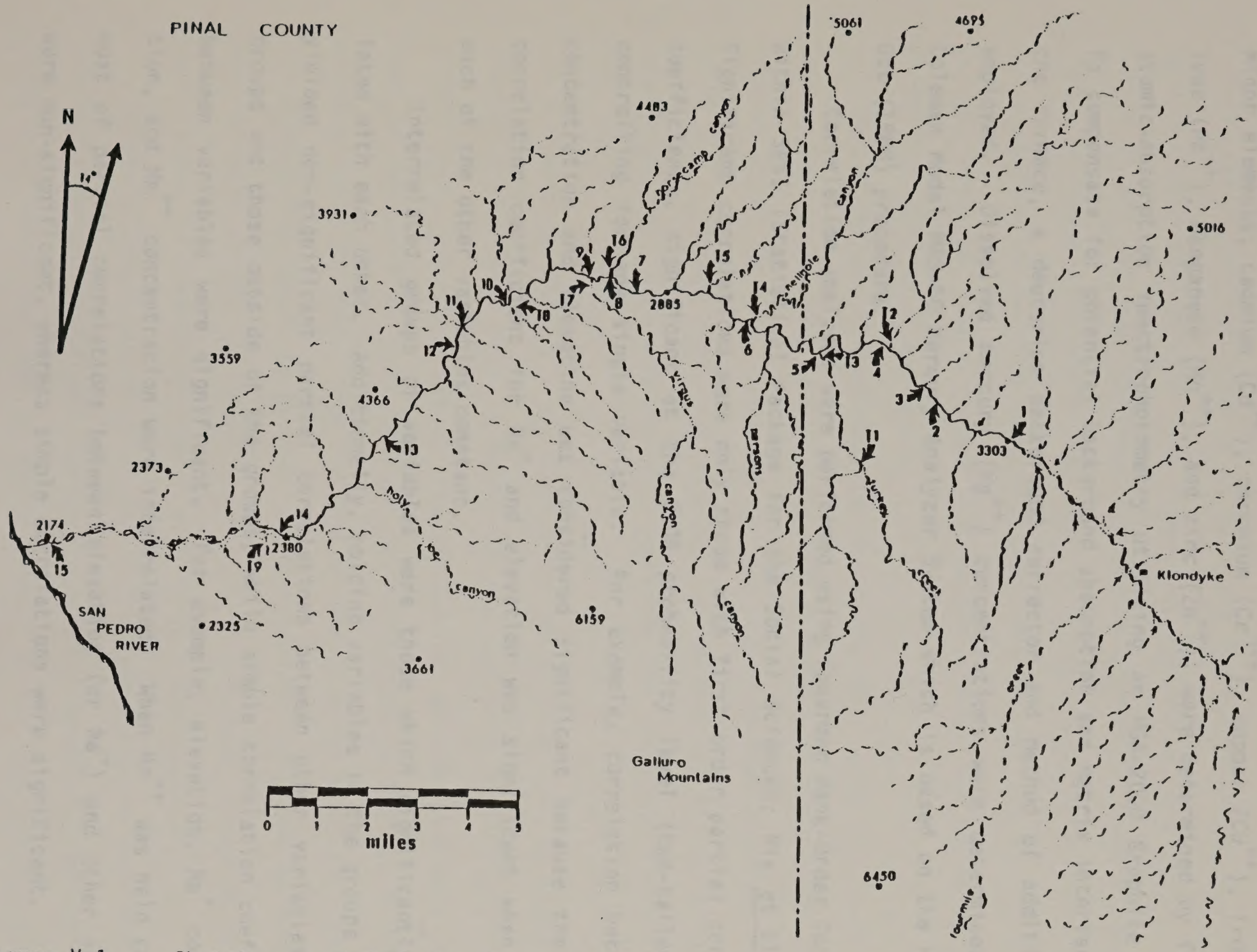

Figure V-1. Sketch map of Aravaipa Creek drainage, Arizona, showing sampling sites in the mainstream (1-15) and in various tributaries (T1-T9).

were analyzed by standard, flame-atomization techniques (Perkin-Elmer 1973). Minor elements, cadmium (Cd^{++}), chromium (Cr^{+++}), copper (Cu^{++}), iron (Fe^{++}), lead (Pb^{++}), manganese (Mn^{++}), and zinc (Zn^{++}), were determined by flameless, atomic-absorption spectrophotometry utilizing an HGA-2000 Graphite Furnace. To compensate for potential background absorption and matrix interferences in the furnace, a deuterium background corrector and method of additions were employed. Dissolved mercury (Hg^{++}) concentrations were determined with a Coleman Model MAS-50 Mercury Analyzer System which is based on the Hatch and Ott (1968) procedure.

Correlation analyses were performed using Spearman Rank-Order Correlation within SPSS (Statistical Package for the Social Sciences; Nie et al. 1975). Significant correlations were only those with first order partial correlation coefficients, significant at the 0.05 probability level (two-tailed), when controlling for any single variable. For example, correlation between Na^+ concentration and elevation was considered significant because the partial correlation coefficient for Na^+ and elevation was significant when holding each of the other variables constant.

Interrelated groups of variables were those which significantly correlated with each other. Additionally, holding variables in the groups constant yielded non-significant partial correlations between other variables in the groups and those outside of the groups, while simple correlation coefficients between variables were significant. For example, elevation, Na^+ concentration, and Mn^{++} concentration were interrelated. When Mn^{++} was held constant, most of partial correlations between elevation (or Na^+) and other variables were non-significant, whereas simple correlations were significant.

3. Results

a. Major Cations - Ca^{++} and Mg^{++} are the cationic components of water hardness that are derived from limestones, dolomites, and gypsum deposits. Waters of the American Southwest are generally high in these elements (Cole 1963), but those of Aravaipa Creek and its tributaries (Tables V-3 - V-9) were not exceptionally so, and were far less concentrated for all major cations (these, plus Na^+ and K^+) than are waters classed as below governmental standard of quality (Table V-10).

During periods of generally low discharge, when water was clear (all but June - August 1976 and January 1977 with reference to the present data; see Section IV for details), dissolved Ca^{++} in the mainstream resembled values for total Ca^{++} (compare Figs. V-2 - V-3). In periods of higher discharge and turbidity, total Ca^{++} significantly exceeded the dissolved fraction (Tables V-3 - V-4).

A tendency for Ca^{++} to decline slightly from up- to downstream in Aravaipa Creek (Fig. V-3), although not statistically significant within the present data, was likely due to precipitation of calcium carbonate ($CaCO_3$) at high pH produced in part through photosynthetic stripping of half-bound carbon-dioxide (as HCO_3^-) from the system (see Cole and Batchelder 1969).

Tributaries tended to be lower in dissolved Ca^{++} than the mainstream, but were variable stream to stream (Table V-9). One major exception was Turkey Creek (Table V-5), which averaged almost 60 mg/l dissolved Ca^{++}.

Values of dissolved and total Ca^{++} for tributaries were even more similar than those in the mainstream (Tables V-5 - V-9), except for Hell Hole Canyon (Table V-9), which was sampled during flood. In the last instance total Ca^{++}

Table V-3. Dissolved chemical characteristics of Aravaipa Creek, Arizona.

Element	$\overline{X}$	SE	MIN	MAX	N
Ca^{++} mg/l	45.038	1.586	17.0	57.4	34
Mg^{++} mg/l	9.309	0.1351	7.3	11.2	34
Na^{+} mg/l	25.432	0.7516	16.0	32.2	34
K^{+} mg/l	3.248	0.1809	1.4	5.8	34
Cr^{+++} µg/l	2.894	0.1680	1.3	5.7	34
Cd^{++} µg/l	0.0944	n.a.[1]	0	0.4	34
Cu^{++} µg/l	3.800	0.3637	1.3	12.5	34
Fe^{++} µg/l	40.218	7.5122	1.5	195.0	34
Mn^{++} µg/l	7.418	0.8751	1.1	18.6	34
Hg^{++} µg/l	5.335	n.a.[1]	0+	75.0	17
Pb^{++} µg/l	1.371	n.a.[1]	0+	6.5	34
Zn^{++} µg/l	24.721	5.1325	1.3	134.0	34

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[1] n.a. = not applicable because undetected quantities in some samples.

Table V-4. Total chemical characteristics of Aravaipa Creek, Arizona.

Element		$\overline{X}$	SE	MIN	MAX	N
Ca^{++}	mg/l	46.503	1.548	27.2	65.0	34
Mg^{++}	mg/l	10.394	0.4822	8.0	25.0	34
Na^{+}	mg/l	30.444	4.316	16.0	170.0	34
K^{+}	mg/l	3.826	0.4017	1.1	15.0	34
Cr^{+++}	µg/l	8.782	2.173	1.0	58.0	34
Cu^{++}	µg/l	9.874	1.603	2.9	42.3	34
Cd^{++}	µg/l	1.084	0.2217	0.05	5.9	34
Fe^{++}	µg/l	2,146.1	832.6	200.0	27,900.0	34
Mn^{++}	µg/l	150.65	70.44	8.8	2,392.0	34
Pb^{++}	µg/l	11.703	4.351	1.3	146.0	34
Zn^{++}	µg/l	124.909	68.768	6.6	2,380.0	34

Table V-5. Chemistry of Turkey Creek (T3, elevation 937.3), Arizona.

Element		$\overline{X}$	SE	MIN	MAX	N
Dissolved concentrations						
Ca^{++}	mg/l	59.475	6.033	42.0	68.0	4
Mg^{++}	mg/l	15.525	0.366	14.5	16.1	4
Na^{+}	mg/l	30.65	0.85	29.0	33.0	4
K^{+}	mg/l	2.75	0.595	1.4	3.8	4
Cr^{+++}	µg/l	2.775	0.69	1.8	4.8	4
Cu^{++}	µg/l	2.95	0.171	2.5	3.3	4
Cd^{++}	µg/l	0.0375	n.a.[1]	0	0.1	4
Fe^{++}	µg/l	34.35	3.767	26.0	44.0	4
Mn^{++}	µg/l	191.85	73.78	31.4	389.0	4
Hg^{++}	µg/l	0.85	0.75	0.1	1.6	2
Pb^{++}	µg/l	0.825	0.225	0.3	1.4	4
Zn^{++}	µg/l	20.55	5.5	7.3	33.8	4
Total Concentrations						
Ca^{++}	mg/l	59.875	5.64	44.0	70.0	4
Mg^{++}	mg/l	15.45	0.585	14.0	16.8	4
Na^{+}	mg/l	31.05	1.225	28.0	34.0	4
K^{+}	mg/l	2.725	0.439	1.8	3.7	4
Cr^{+++}	µg/l	7.35	3.559	1.5	17.0	4
Cu^{++}	µg/l	5.075	1.23	1.7	7.2	4
Cd^{++}	µg/l	0.62	n.a.[1]	0	2.1	4
Fe^{++}	µg/l	157.5	37.94	100.0	260.0	4
Mn^{++}	µg/l	379.75	93.8	190.0	630.0	4
Pb^{++}	µg/l	6.475	2.19	1.7	10.9	4
Zn^{++}	µg/l	67.0	37.18	19.0	176.0	4

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[1] n.a. = not applicable because of undetected quantities in some samples.

Table V-6. Chemistry of Horse Camp Canyon (T6, elevation 883.9 m), Arizona.

Element		$\overline{X}$	SE	MIN	MAX	N
Dissolved concentrations						
Ca^{++}	mg/l	22.0	2.646	18.0	27.0	3
Mg^{++}	mg/l	4.067	0.348	3.5	4.7	3
$Na+$	mg/l	33.73	6.293	21.2	41.0	3
K^{+}	mg/l	3.8	0.666	2.5	4.7	3
Cr^{+++}	µg/l	2.067	0.393	1.3	2.6	3
Cu^{++}	µg/l	4.0	1.415	1.6	6.5	3
Cd^{++}	µg/l	0.12	n.a.[1]	0	0.3	3
Fe^{++}	µg/l	177.0	95.8	32.0	358.0	3
Mn^{++}	µg/l	16.33	14.33	1.5	45.0	3
Hg^{++}	µg/l	0.46	-	-	-	1
Pb^{++}	µg/l	0.93	0.219	0.5	1.2	3
Zn^{++}	µg/l	51.5	29.22	7.9	107.0	3
Total concentration						
Ca^{++}	mg/l	22.53	2.272	19.0	28.0	3
Mg^{++}	mg/l	4.33	0.203	4.0	4.7	3
Na^{+}	mg/l	90.2	61.11	20.9	212.0	3
K^{+}	mg/l	3.83	0.467	2.9	4.3	3
Cr^{+++}	µg/l	5.13	0.780	3.8	6.5	3
Cu^{++}	µg/l	9.8	2.403	5.0	12.4	3
Cd^{++}	µg/l	0.393	0.0636	0.28	0.5	3
Fe^{++}	µg/l	760.0	595.8	110.0	1,950.0	3
Mn^{++}	µg/l	126.7	62.83	23.0	240.0	3
Pb^{++}	µg/l	7.73	4.604	2.4	16.9	3
Zn^{++}	µg/l	35.6	11.285	12.0	48.0	3

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[1] n.a. = not applicable because of undetected quantities in some samples.

Table V-7. Chemistry of Virgus Canyon (T7, elevation 883.9m), Arizona.

Element		$\overline{X}$	SE	MIN	MAX	N
Dissolved concentrations						
Ca^{++}	mg/l	26.0	-	25.0	27.0	2
Mg^{++}	mg/l	9.55	-	8.6	10.5	2
Na^{+}	mg/l	12.45	-	8.9	16.0	2
K^{+}	mg/l	3.3	-	3.2	3.4	2
Cr^{+++}	µg/l	4.95	-	3.0	6.9	2
Cu^{++}	µg/l	2.8	-	2.2	3.4	2
Cd^{++}	µg/l	0.325	-	0.05	0.6	2
Fe^{++}	µg/l	32.5	-	32.0	33.0	2
Mn^{++}	µg/l	18.0	-	15.6	20.4	2
Hg^{++}	µg/l	2.7	-	-	-	1
Pb^{++}	µg/l	1.55	-	1.4	1.7	2
Zn^{++}	µg/l	64.1	-	4.2	124.0	2
Total concentrations						
Ca^{++}	mg/l	32.3	7.006	28.0	46.0	3
Mg^{++}	mg/l	11.17	1.705	8.3	14.2	3
Na^{+}	mg/l	14.33	2.603	10.0	19.0	3
K^{+}	mg/l	4.67	1.172	3.3	7.0	3
Cr^{+++}	µg/l	3.25	0.1893	2.95	3.6	3
Cu^{++}	µg/l	5.77	1.774	2.5	8.6	3
Cd^{++}	µg/l	0.707	0.4539	0.12	1.6	3
Fe^{++}	µg/l	303.0	205.9	10.0	700.0	3
Mn^{++}	µg/l	174.4	157.8	16.2	490.0	3
Pb^{++}	µg/l	3.27	0.6960	2.0	4.4	3
Zn^{++}	µg/l	90.5	75.21	1.5	240.0	3

Table V-8. Chemistry of unnamed tributary (T9, 701.6 m) of Aravaipa Creek, Arizona.

Element		$\overline{X}$	MIN	MAX	N
Dissolved concentrations					
Ca^{++}	mg/l	50.0	50.0	50.0	2
Mg^{++}	mg/l	10.05	9.9	10.2	2
Na^{+}	mg/l	28.5	24.0	33.0	2
K^{+}	mg/l	5.2	5.1	5.3	2
Cr^{+++}	µg/l	3.1	2.8	3.4	2
Cu^{++}	µg/l	2.15	1.2	3.1	2
Cd^{++}	µg/l	0.235	0	0.47	2
Fe^{++}	µg/l	31.25	12.5	50.0	2
Mn^{++}	µg/l	3.325	3.25	3.4	2
Hg^{++}	µg/l	5.0	5.0	5.0	2
Pb^{++}	µg/l	0.35	0.3	0.4	2
Zn++	µg/l	15.9	15.0	16.8	2
Total concentrations					
Ca^{++}	mg/l	49.5	49.0	50.0	2
Mg^{++}	mg/l	10.25	10.2	10.3	2
Na^{+}	mg/l	28.0	28.0	28.0	2
K^{+}	mg/l	5.7	4.3	5.1	2
Cr^{+++}	µg/l	4.0	3.5	4.5	2
Cu^{++}	µg/l	10.5	9.2	11.8	2
Cd^{++}	µg/l	0.025	0	0.05	2
Fe^{++}	µg/l	1,440.0	1,050.0	1,750.0	2
Mn^{++}	µg/l	51.0	51.0	51.0	2
Pb^{++}	µg/l	5.5	4.7	6.3	2
Zn^{++}	µg/l	51.1	12.2	90.0	2

Table V-9. Chemistry of several tributaries of Aravaipa Creek, Arizona, based on single samples.

SITE[1]		T1	T2	T4	T5	T8
ELEV.		976.9 m	961.6 m	914.4 m	899.2 m	829.1 m
MONTH		Jan	Oct	Aug	Jan	Jan
Dissolved concentrations						
Ca^{++}	mg/l	60.9	46.0	29.0	35.0	19.0
Mg^{++}	mg/l	16.1	8.7	3.5	11.2	3.9
Na^{+}	mg/l	30.6	19.0	9.0	28.8	9.8
K^{+}	mg/l	1.4	4.0	2.3	2.9	2.8
Cr^{+++}	µg/l	4.8	4.2	1.2	3.7	2.6
Cu^{++}	µg/l	2.5	4.5	10.4	3.4	5.0
Cd^{++}	µg/l	0.05	0.18	0.3	0.16	0.2
Fe^{++}	µg/l	36.0	1,390.0	56.0	18.0	31.0
Mn^{++}	µg/l	192.0	5.9	2.2	2.2	2.0
Hg^{++}	µg/l	0.1	-	-	1.58	0.7
Pb^{++}	µg/l	0.8	0.2	1.7	0.7	1.1
Zn^{++}	µg/l	7.3	171.0	53.0	5.1	2.8
Total concentration						
Ca^{++}	mg/l	60.5	49.0	108.0	34.6	20.5
Mg^{++}	mg/l	16.8	9.6	38.5	11.2	4.0
Na^{+}	mg/l	31.2	15.0	12.0	28.9	8.6
K^{+}	mg/l	1.8	4.0	10.2	3.6	3.1
Cr^{+++}	µg/l	17.0	5.9	20.0	3.9	2.4
Cu^{++}	µg/l	6.5	5.5	1,810.0	3.0	8.0
Cd^{++}	µg/l	2.1	0.1	62.7	1.1	0.25
Fe^{++}	µg/l	170.0	5,050.0	54,000.0	130.0	100.0
Mn^{++}	µg/l	190.0	92.0	21,600.0	9.8	5.8
Pb^{++}	µg/l	9.4	5.4	5,500.0	1.5	2.0
Zn^{++}	µg/l	20.0	37.7	8,670.0	19.0	22.0

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[1] T2-Mid Turkey Creek; T2-mouth of Bear Canyon; T4-Hell Hole Canyon; T5-Paisano Canyon, 1/4 mi above mouth; T8-Hell's Half Acre.

Table V-10. Surface water criteria for public water supplies and maintenance of "healthy" aquatic environments (by government agency).

Element	USHEW: Drinking Water Standards (1962)	US FWPCA: Water Quality Criteria (1968)	WHO: International Standards, Drinking Water (1971)	US EPA: Water Quality Criteria (1972)	US EPA: Quality Criteria for Water-Domestic Supply (1976)	US EPA: Quality Criteria for Water-freshwater Aquatic Life (1976)
Cd^{++}	10 μg/l	10 μg/l	10 μg/l	10 μg/l	10 μg/l	Soft water/Hard water 0.4 μg/l 1.2 μg/l for cladocerand salm. fish 4.0 μg/l 12.0 μg/l for less sensitive aquatic life
Ca^{++}	-	-	200 mg/l	-	-	
Cr^{+++}	50 μg/l	50 μg/l	-	50 μg/l	50 μg/l	100 μg/l
Cu^{++}	1 mg/l	1 mg/l	1.5 mg/l	1 mg/l	1 mg/l	0.1 of 96-hr LC-50 Value[1]
Fe^{++}	300 μg/l	300 μg/l	1000 μg/l	300 μg/l	300 μg/l	1.0 mg/l
Pb^{++}	50 μg/l	50 μg/l	100 μg/l	50 μg/l	50 μg/l	0.01 of 96-hr LC-50 Value[2]
Mg^{++}	-	-	150 mg/l	-	-	-
MN^{++}	50 μg/l	50 μg/l	500 μg/l	50 μg/l	50 μg/l	-
Hg^{++}	-	-	1 μg/l	2 μg/l	2 μg/l	0.05 μg/l
K^{+}	-	-	-	-	-	-
Na^{+}	-	-	-	-	-	-
Zn^{++}	5 mg/l	5 mg/l	15 mg/l	5 mg/l	5 mg/l	0.01 of 96-hr LC-50 Value[3]

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[1] As determined through non-aerated bioassay using a sensitive aquatic resident species.

[2] Using the receiving or comparable water as a dilutent and soluble lead measurement (non-filtrable lead using a 0.45 m/m filter), for "sensitive" freshwater resident species.

[3] As determined through bioassay using a "sensitive" aquatic resident species.

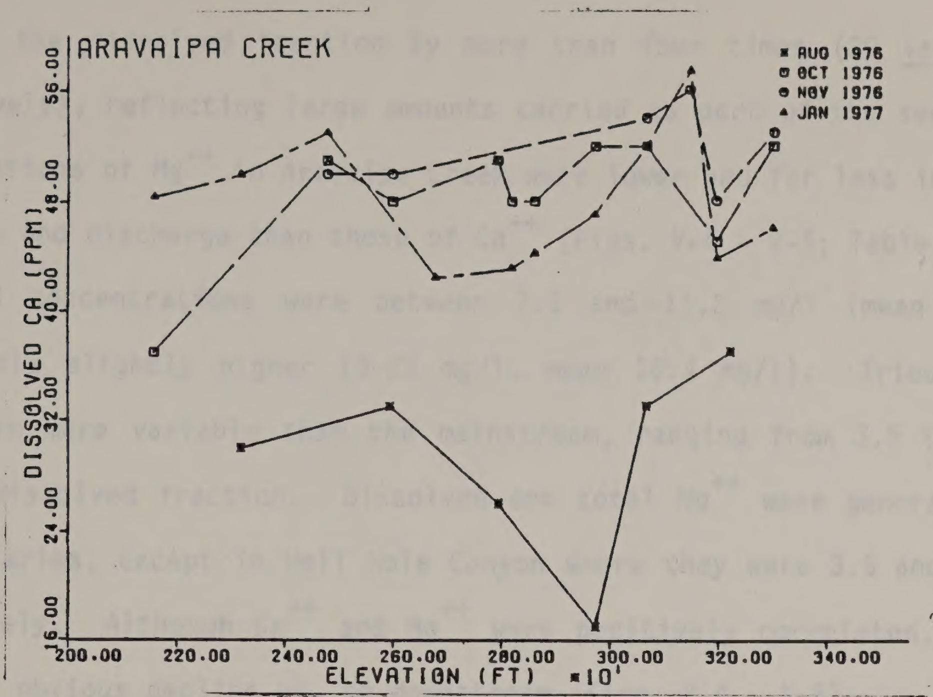

Figure V-2. Dissolved Ca^{++} concentrations in Aravaipa Creek, Arizona.

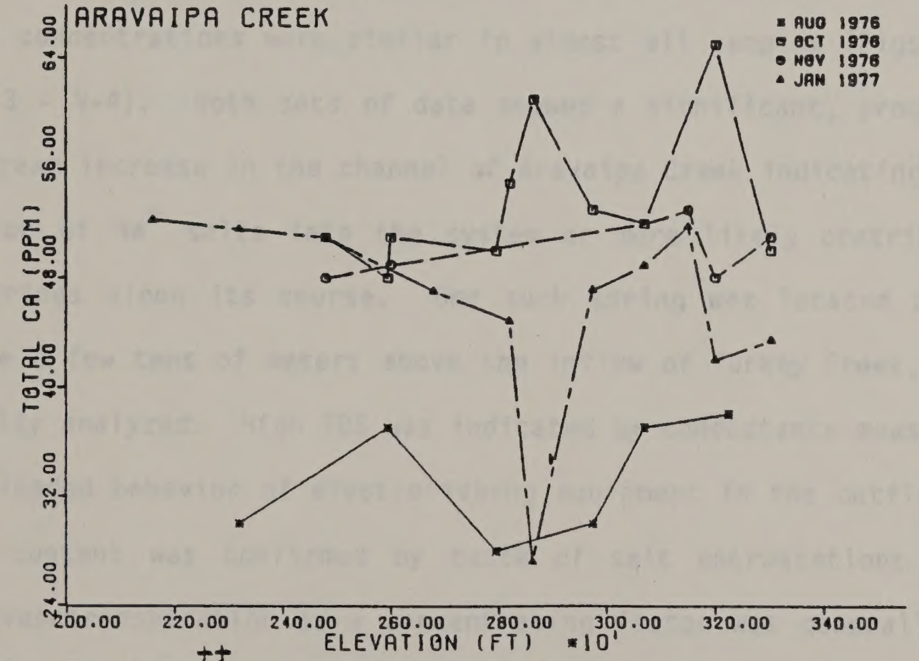

Figure V-3. Total Ca^{++} concentrations in Aravaipa Creek, Arizona.

exceeded the dissolved fraction by more than four times (29 vs. 108 mg/l, respectively), reflecting large amounts carried as part of the sediment load. Concentrations of Mg^{++} in Aravaipa Creek were lower and far less influenced by elevation and discharge than those of Ca^{++} (Figs. V-4 - V-5; Table V-3 - V-4). Dissolved concentrations were between 7.3 and 11.2 mg/l (mean 9.3), with totals only slightly higher (8-25 mg/l, mean 10.4 mg/l). Tributary waters were again more variable than the mainstream, ranging from 3.5 to 16.1 mg/l for the dissolved fraction. Dissolved and total Mg^{++} were generally similar in tributaries, except in Hell Hole Canyon where they were 3.5 and 38.5 mg/l, respectively. Although Ca^{++} and Mg^{++} were positively correlated, the latter showed no obvious decline up- to downstream (Figs. V-4 - V-5).

Na^{+} is a far more soluble ion than the two just discussed, and dissolved and total concentrations were similar in almost all samples (Figs. V-6 - V-7, Tables V-3 - V-4). Both sets of data showed a significant, progressive, up- to downstream increase in the channel of Aravaipa Creek indicating dissolution and erosion of Na^{+} salts into the system or more likely contributions from saline springs along its course. One such spring was located on the north cliff face a few tens of meters above the inflow of Turkey Creek, but was not specifically analyzed. High TDS was indicated by conductance measurements and the over-loaded behavior of electrofishing equipment in the outflow area, and high Na^{+} content was confirmed by taste of salt encrustations and seeping water. Evapotranspiration as a concentrating factor was generally ruled out since other major cations showed no such pattern.

A "spike" in concentration of total Na^{+} in the mainstream in October (Fig. V-7) was unusual. Similarly high concentrations of other elements (Mg^{++}, Fe^{++}, Mn^{++}, and Zn^{++}) tended to negate possibilities for sample

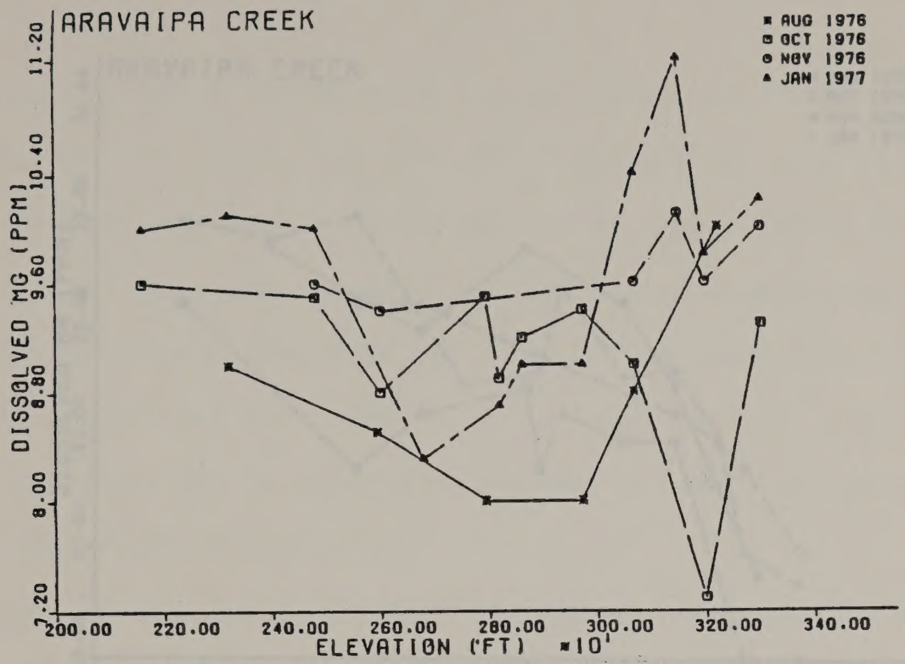

Figure V-4. Dissolved Mg^{++} concentrations in Aravaipa Creek, Arizona.

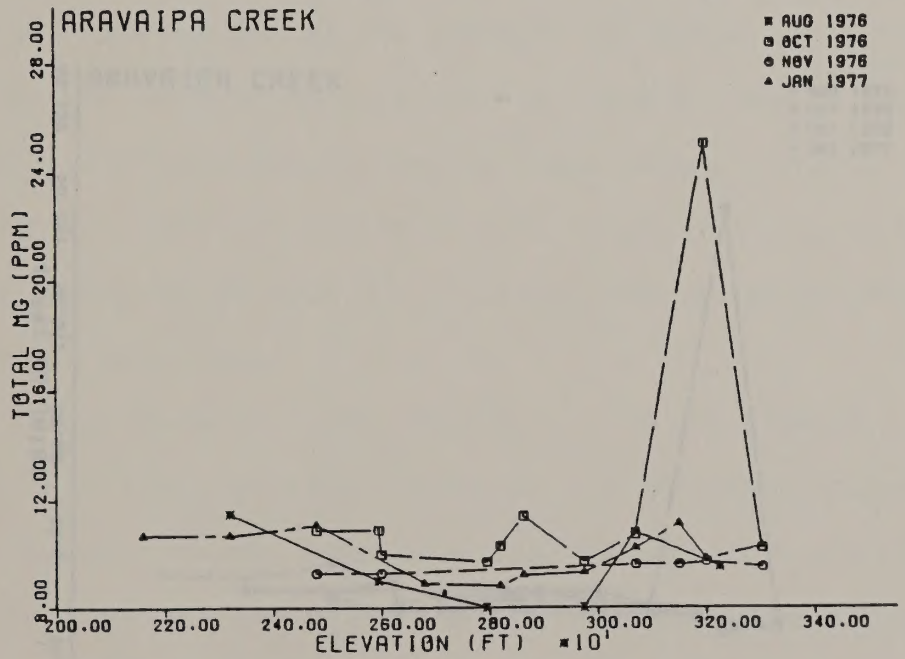

Figure V-5. Total Mg^{++} concentrations in Aravaipa Creek, Arizona.

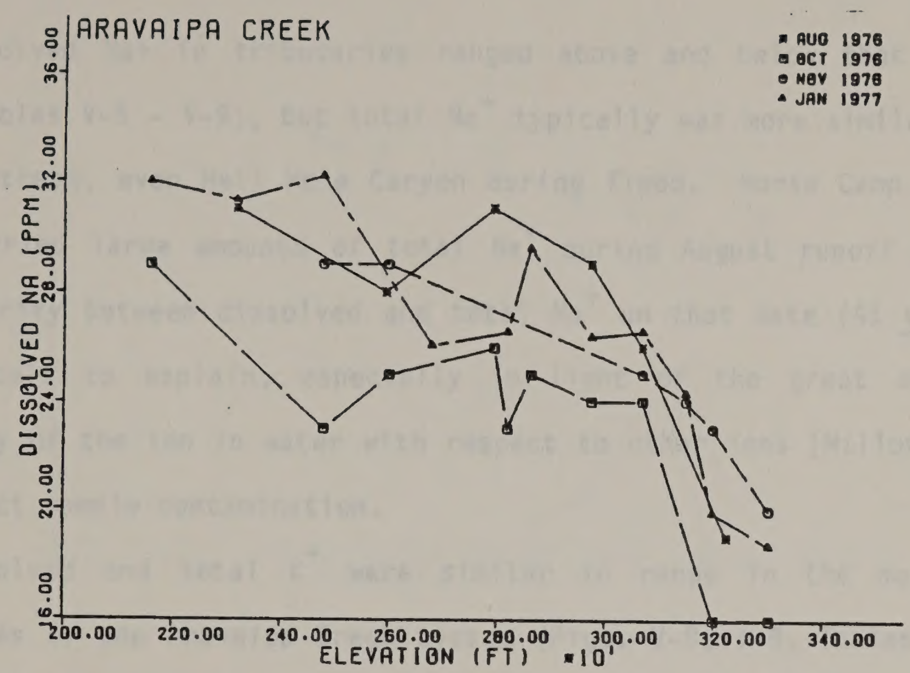

Figure V-6. Dissolved Na^{+} concentrations in Aravaipa Creek, Arizona.

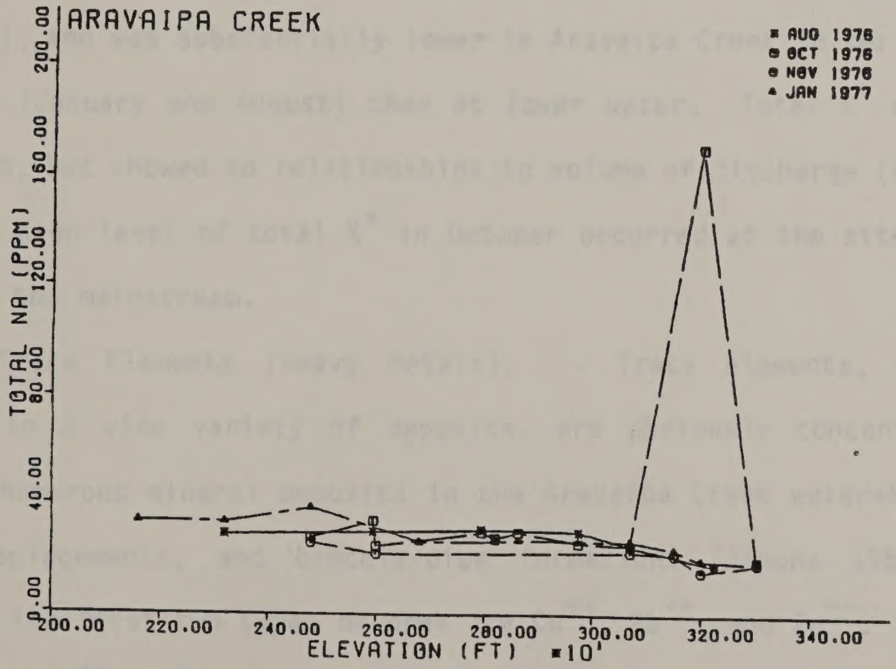

Figure V-7. Total N^{a}=+ concentrations in Aravaipa Creek, Arizona.

contamination, and indicate an unexpected source of input to the system (see later).

Dissolved Na+ in tributaries ranged above and below that in Aravaipa Creek (Tables V-5 - V-9), but total Na^+ typically was more similar to that in the mainstream, even Hell Hole Canyon during flood. Horse Camp Canyon, however, carried large amounts of total Na^+ during August runoff (Table V-6). The disparity between dissolved and total Na^+ on that date (41 vs. 212 mg/l) is difficult to explain, especially in light of the great and selective solubility of the ion in water with respect to other ions (Millott 1970), and may reflect sample contamination.

Dissolved and total K^+ were similar in range in the mainstream and tributaries of the Aravaipa Creek system (Figs. V-8, V-9, Tables V-3 - V-9), and little difference was apparent between the two measurements. Dissolved K^+ behaved the same as Na^+ in the channel, increasing significantly downflow (Fig. V-8), and was substantially lower in Aravaipa Creek in periods of higher discharge (January and August) than at lower water. Total K^+ also increased downstream, but showed no relationships to volume of discharge (Fig. V-9). An unusually high level of total K^+ in October occurred at the site below Maroga Canyon in the mainstream.

b. Trace Elements (Heavy Metals). - Trace elements, although distributed in a wide variety of deposits, are obviously concentrated in ore bodies. Numerous mineral deposits in the Aravaipa Creek watershed consist of veins, replacements, and breccia-pipe formations (Simons 1964). Primary metals of the first two types of ores are Cu^{++}, Pb^{++}, and Zn^{++}. Breccia-pipes are mostly Cu^{++} and molybdenum. Deposits are quartz-sulfide bodies along faults in volcanic strata (Simons 1964). The common sulfide minerals are

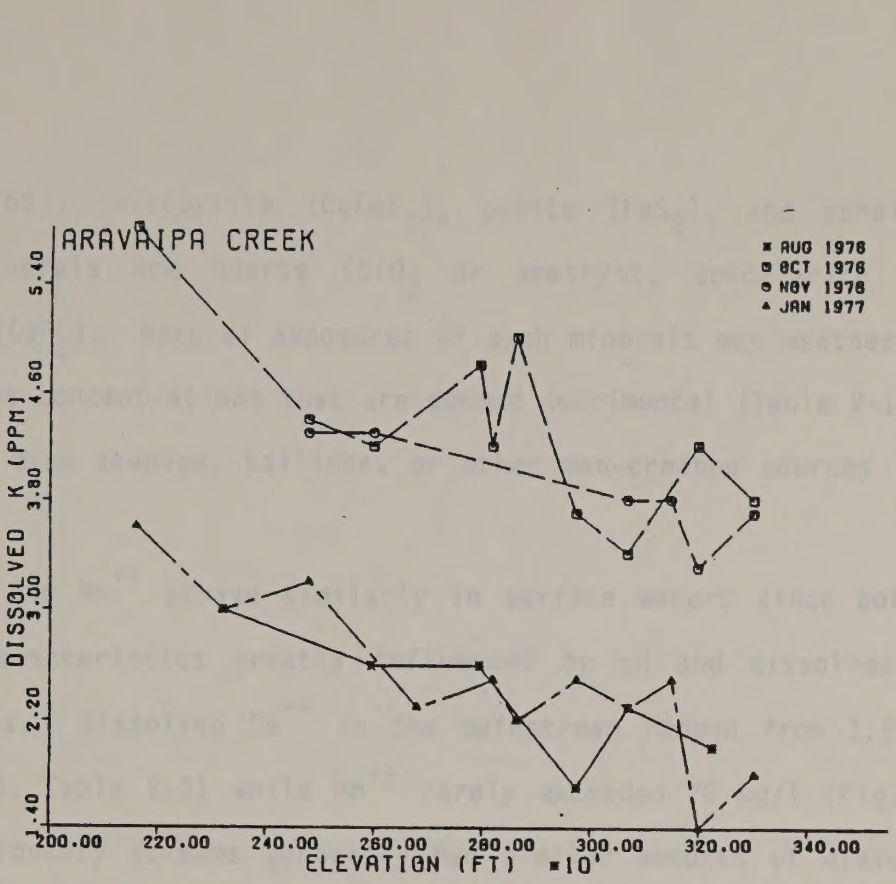

Figure V-8. Dissolved K$^+$ concentrations in Aravaipa Creek, Arizona.

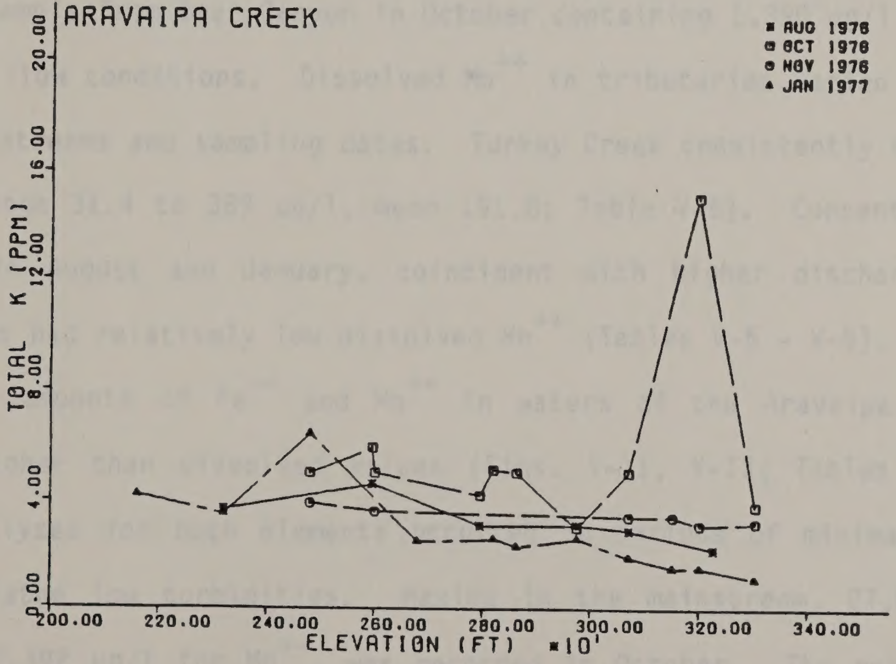

Figure V-9. Total K$^+$ concentrations in Aravaipa Creek, Arizona.

galena (PbS), calcopyrite ($CuFeS_2$), pyrite (FeS_2), and sphalerite (ZnS). Gaunge minerals are quarts (SiO_2 or amethyst, specularite (Fe_2O_3), and flourite (CaF_2). Natural exposures of such minerals may weather into surface waters, but concentrations that are deemed detrimental (Table V-10) most often come from mine seepage, tailings, or other man-created sources (see Appendix C).

Fe^{++} and Mn^{++} behave similarly in surface waters since both have solubility characteristics greatly influenced by pH and dissolved oxygen concentrations. Dissolved Fe^{++} in the mainstream ranged from 1.5 to 195 µg/l (Fig. V-10, Table V-3) while Mn^{++} rarely exceeded 20 µg/l (Fig. V-12, Table V-3). Tributary streams generally had similar amounts of dissolved Fe^{++} as the mainstream (Tables V-5 - V-9), with Horse Camp Canyon (Table V-6) ranging to 358 µg/l in August in association with high runoff from its watershed, and a single sample from Bear Canyon in October containing 1,390 µg/l (Table V-9), under low flow conditions. Dissolved Mn^{++} in tributaries varied widely among different streams and sampling dates. Turkey Creek consistently had high Mn^{++} values (range 31.4 to 389 µg/l, mean 191.8; Table V-5). Concentrations were greatest in August and January, coincident with higher discharges. Other tributaries had relatively low dissolved Mn^{++} (Tables V-6 - V-9).

Total amounts of Fe^{++} and Mn^{++} in waters of the Aravaipa system were notably higher than dissolved values (Figs. V-11, V-13; Tables V-3 - V-9). Lowest analyses for both elements occurred in periods of minimal discharges and associated low turbidities. Maxima in the mainstream, 27,900 µg/l for Fe^{++} and 2,392 µg/l for Mn^{++}, was recorded in October. The relatively high means for each element in Aravaipa Creek (Table V-4) reflect high concentrations in August floods, and in October under low flow conditions (Figs.

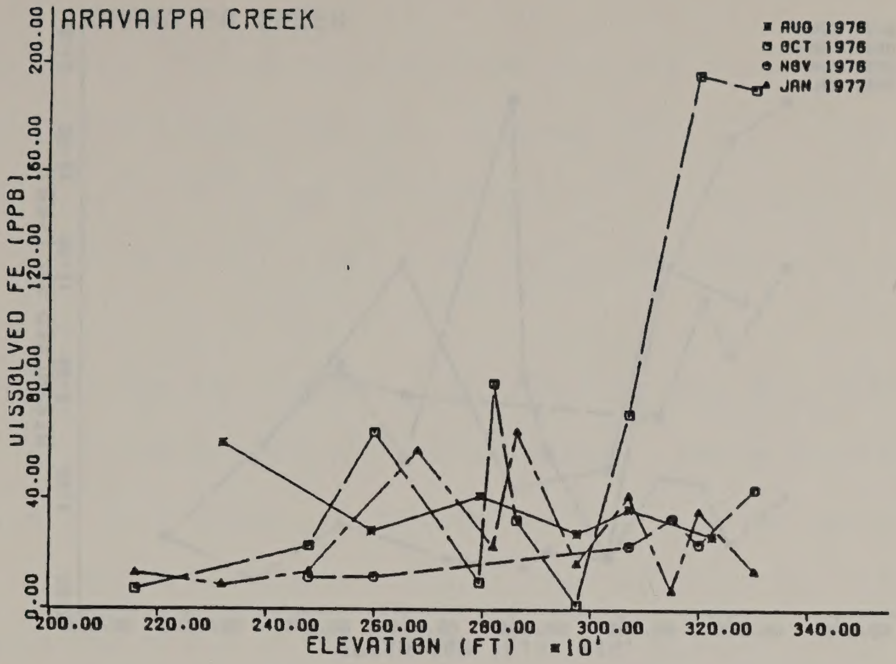

Figure V-10. Dissolved Fe^{++} concentrations in Aravaipa Creek, Arizona.

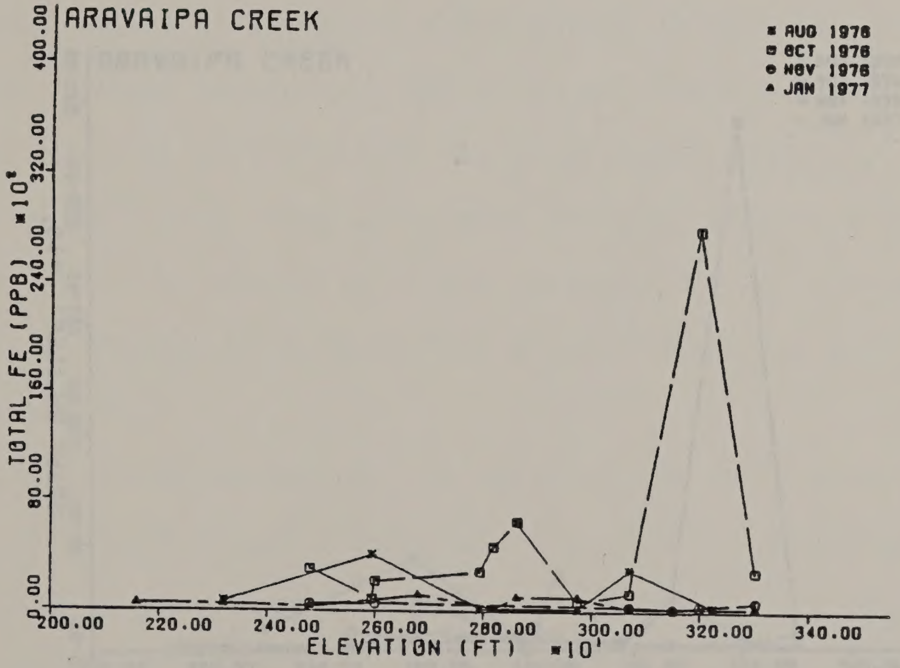

Figure V-11. Total Fe^{++} concentrations in Aravaipa Creek, Arizona.

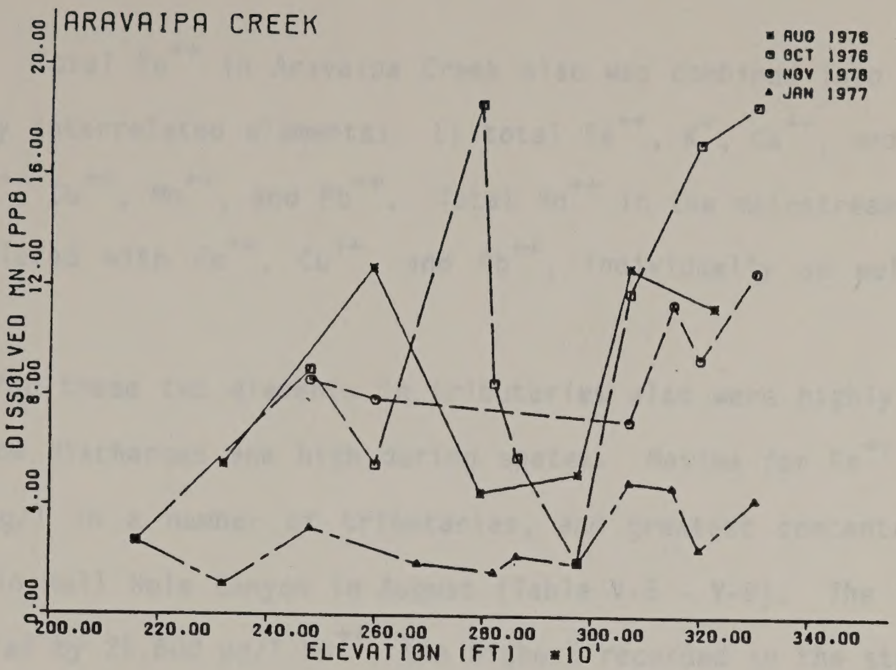

Figure V-12. Dissolved Mn^{++} concentrations in Aravaipa Creek, Arizona.

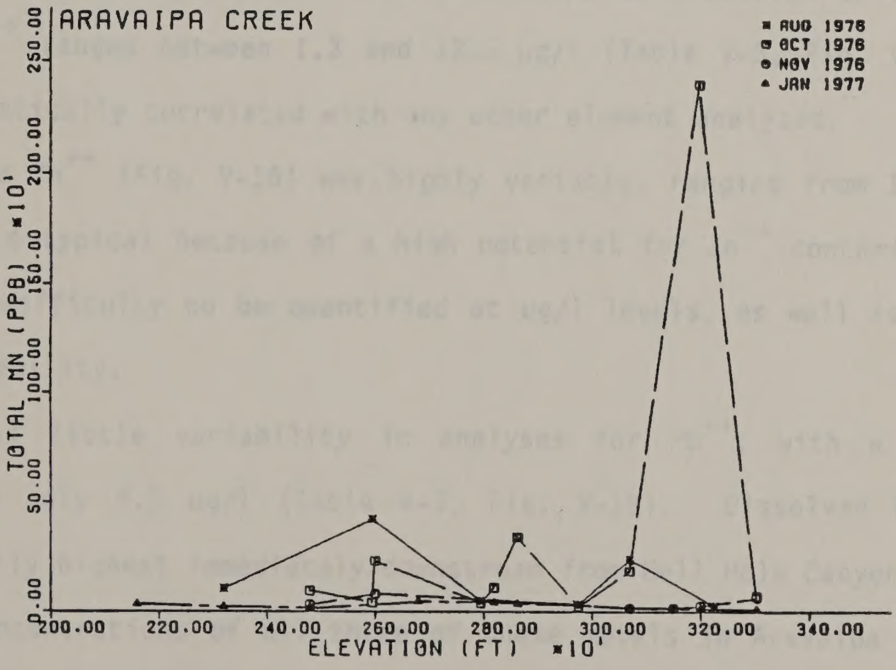

Figure V-13. Total Mn^{++} concentrations in Aravaipa Creek, Arizona.

V-11, V-13). Total Fe^{++} in Aravaipa Creek also was combined into two groups of positively interrelated elements: 1) total Fe^{++}, K^{+}, Ca^{++}, and Mg^{++}; and 2) total Fe^{++}, Cu^{++}, Mn^{++}, and Pb^{++}. Total Mn^{++} in the mainstream was positively correlated with Fe^{++}, Cu^{++}, and Pb^{++}, individually as well as when grouped.

Totals for these two elements in tributaries also were highly variable, low during low discharges and high during spates. Maxima for Fe^{++} were more than 1,000 µg/l in a number of tributaries, and greatest concentration was 54,000 µg/l in Hell Hole Canyon in August (Table V-6 - V-9). The last value was accompanied by 21,600 µg/l Mn^{++}, the highest recorded in the study (Table V-9). Total Mn^{++} in tributaries otherwise did not exceed 630 µg/l.

Distribution of concentrations of dissolved Cu^{++} in the mainstream of Aravaipa Creek showed little or no relationships to elevation or discharge. Dissolved Cu^{++} ranged between 1.3 and 12.5 µg/l (Table V-3, Fig. V-14), and was not statistically correlated with any other element analyzed.

Dissolved Zn^{++} (Fig. V-16) was highly variable, ranging from 1.3 to 134 µg/l. This is typical because of a high potential for Zn^{++} contamination of samples, its difficulty to be quantified at µg/l levels, as well as its wide natural availability.

There was little variability in analyses for Pb^{++}, with a range of undetected to only 6.5 µg/l (Table V-3, Fig. V-18). Dissolved Pb^{++} was, however, usually highest immediately downstream from Hell Hole Canyon.

Total concentrations of all three of these metals in Aravaipa Creek was far higher than the dissolved fractions (Tables V-4, Figs. V-15, V-17 and V-19). Correlations for total Cu^{++} were positive with total Mn^{++}, and in a group with Fe^{++}, Mn^{++}, and Pb^{++}. Total Zn^{++} did not correlate with any other

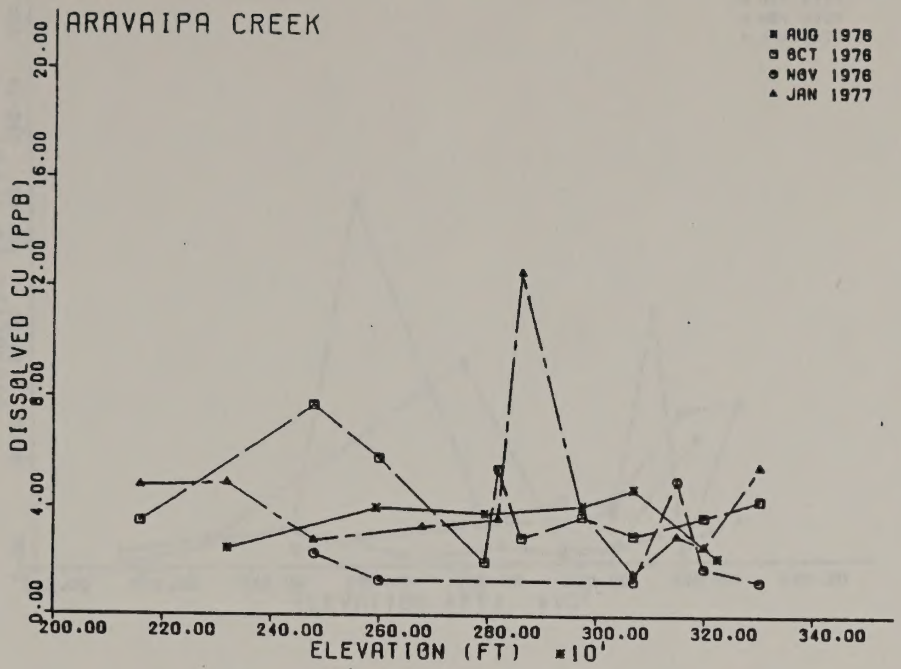

Figure V-14. Dissolved Cu^{++} concentrations in Aravaipa Creek, Arizona.

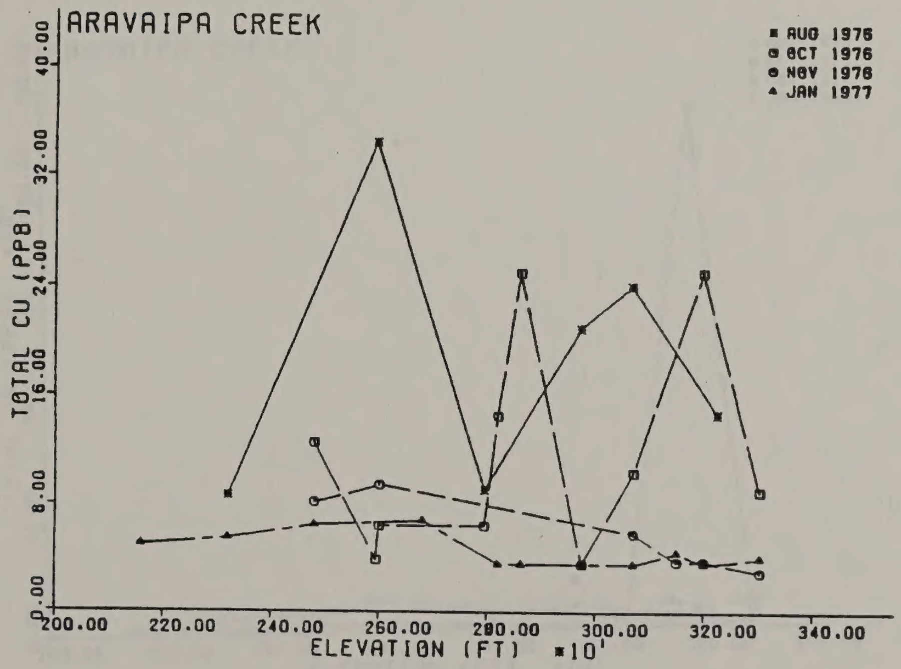

Figure V-15. Total Cu^{++} concentrations in Aravaipa Creek, Arizona.

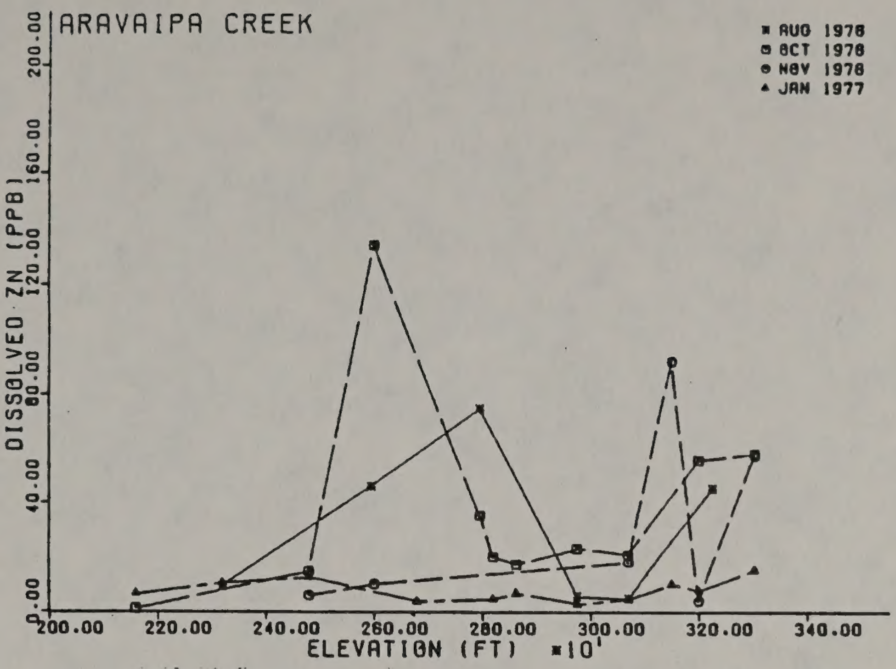

Figure V-16. Dissolved Zn^{++} concentrations in Aravaipa Creek, Arizona

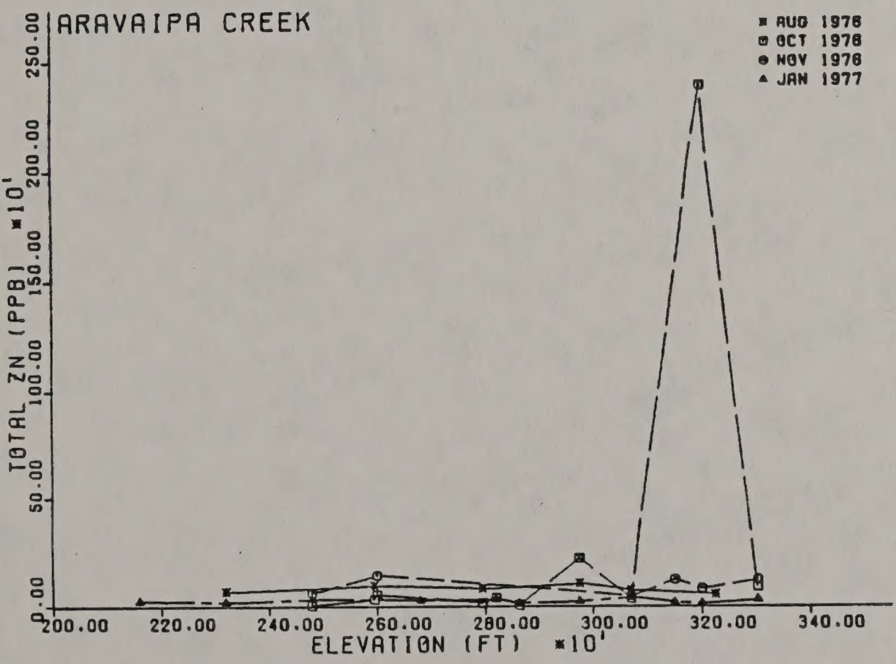

Figure V-17. Total Zn^{++} concentrations in Aravaipa Creek, Arizona

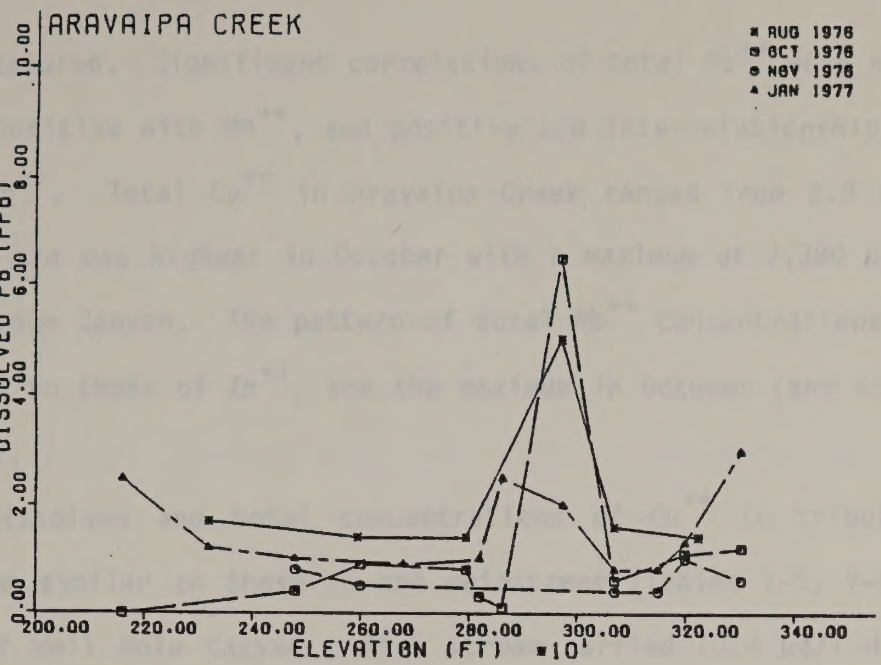

Figure V-18. Dissolved Pb^{++} concentrations in Aravaipa Creek, Arizona.

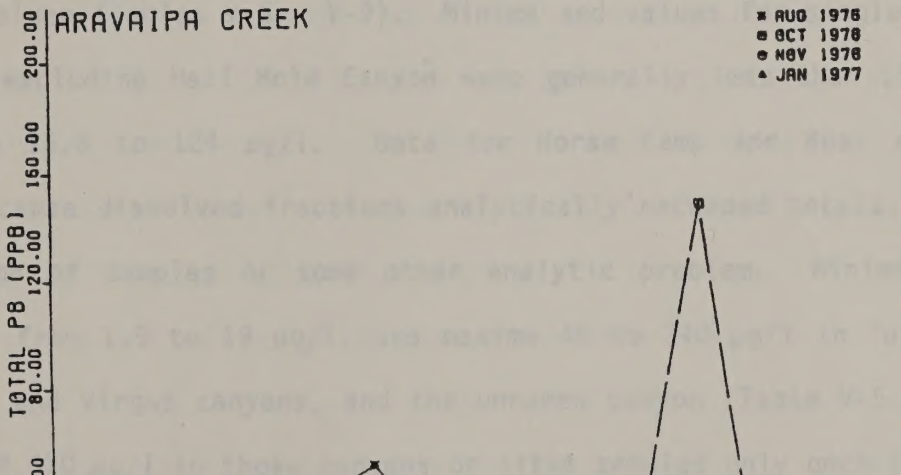

Figure V-19. Total Pb^{++} concentrations in Aravaipa Creek, Arizona.

parameter measured. Significant correlations of total Pb^{++} were negative with discharge, positive with Mn^{++}, and positive and interrelationships with Cu^{++}, Fe^{++}, and Mn^{++}. Total Cu^{++} in Aravaipa Creek ranged from 2.9 to 42.3 µg/l (Table V-4) and was highest in October with a maximum of 2,380 µg/l near the mouth of Maroga Canyon. The pattern of total Pb^{++} concentrations (Fig. V-19) were similar to those of Zn^{++}, and the maximum in October (and for the study) was 146 µg/l.

Both dissolved and total concentrations of Cu^{++} in tributary streams tended to be similar to those in the mainstream (Tables V-5, V-9), with the exception of Hell Hole Canyon. That stream carried 10.4 µg/l dissolved and 1810 µg/l total Cu^{++} in August (Table V-9), indicating a large quantity of Cu^{++} bound on particles carried from that watershed during surface runoff.

Total Zn^{++} concentrations in tributaries were far more variable than dissolved values (Tables V-5 - V-9). Minima and values for single samples at four sites excluding Hell Hole Canyon were generally less than 15 µg/l, and maxima were 16.8 to 124 µg/l. Data for Horse Camp and Bear canyons are excluded because dissolved fractions analytically exceeded totals, signifying contamination of samples or some other analytic problem. Minima for total Zn^{++} ranged from 1.5 to 19 µg/l, and maxima 48 to 240 µg/l in Turkey Creek, Horse Camp, and Virgus canyons, and the unnamed canyon (Table V-5 - V-8), and from 20 to 8,670 µg/l in those canyons or sites sampled only once (Table V-9). The highest value was again in Hell Hole Canyon in August.

Most analyses for dissolved Pb^{++} in tributaries indicated means of less than 1.0 µg/l, with exceptions of Virgus and Hell Hole canyons. Total Pb^{++} followed a pattern identical to that of total Zn^{++}, averaging less than 10

µg/l in all but Hell Hole Canyon, where 5,500 µg/l was recorded (Tables V-5 - V-9).

Values for dissolved Cr^{+++} ranged from 1.3 to 5.8 µg/l in Aravaipa Creek (mean 2.9 µg/l; Table V-3), and from 1.2 to 6.9 in tributaries (Tables V-5 - V-9). In the mainstream it correlated positively with elevation and discharge (Fig. V-20), and also with Mg^{++} and Cd^{++}. Total Cr^{+++} in Aravaipa Creek was from 1.0 to 58 µg/l (average 8.8), with highest concentrations in the upper reaches (Fig. V-21), corresponding with high values in Turkey Creek (Table V-5). Total Cr^{+++} in Hell Hole Canyon during flood (20 µg/l) scarcely exceeded maxima values of 17 µg/l for Turkey Creek during normal and low discharges (Tables V-5, V-9).

Cd^{++} concentrations ranged from undetected to 0.4 µg/l in the dissolved state in Aravaipa Creek (Table V-3, Fig. V-22) and did not exceed 1.0 µg/l in tributaries (Tables V-5 - V-9). Total Cd^{++} averaged 1.1 µg/l in the mainstream (Table V-4, Fig. V-23) and ranged to only 62.7 µg/l in Hell Hole Canyon during flood; most total values in tributaries were far less than 1.0 µg/l.

Levels of dissolved Hg^{++} were similarly low in the mainstream of Aravaipa Creek typically ($<$ 0.4 µg/l; Fig. V-24), with the exception of a November sample of the mouth of Maroga Canyon that contained 75 µg/l (Table V-3). However, some samples from Turkey Creek and Virgus, unnamed, and Parsons canyons contained more than 1.0 µg/l (Tables V-5 - V-9). No determinations were made for total Hg^{++} concentrations, and too few samples of dissolved Hg^{++} were run for statistical treatment.

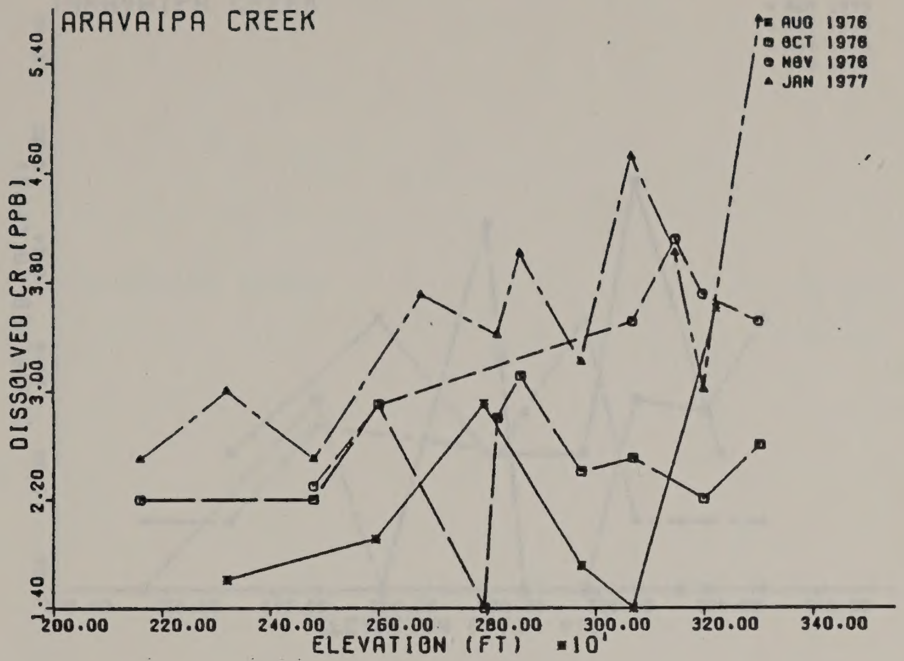

Figure V-20. Dissolved Cr^{+++} concentrations in Aravaipa Creek, Arizona.

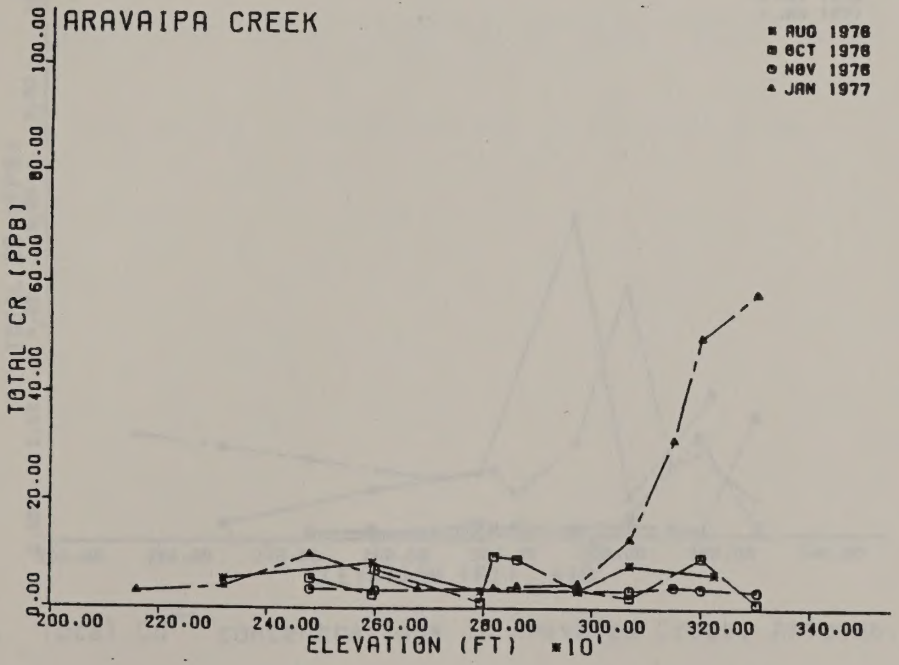

Figure V-21. Total Cr^{+++} concentrations in Aravaipa Creek, Arizona.

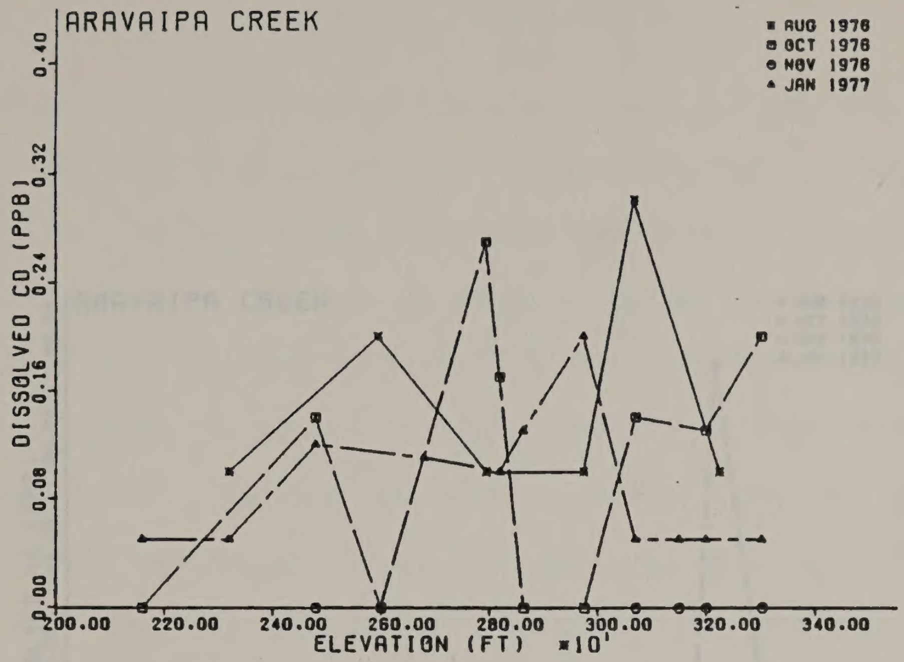

Figure V-22. Dissolved Cd^{++} concentrations in Aravaipa Creek, Arizona.

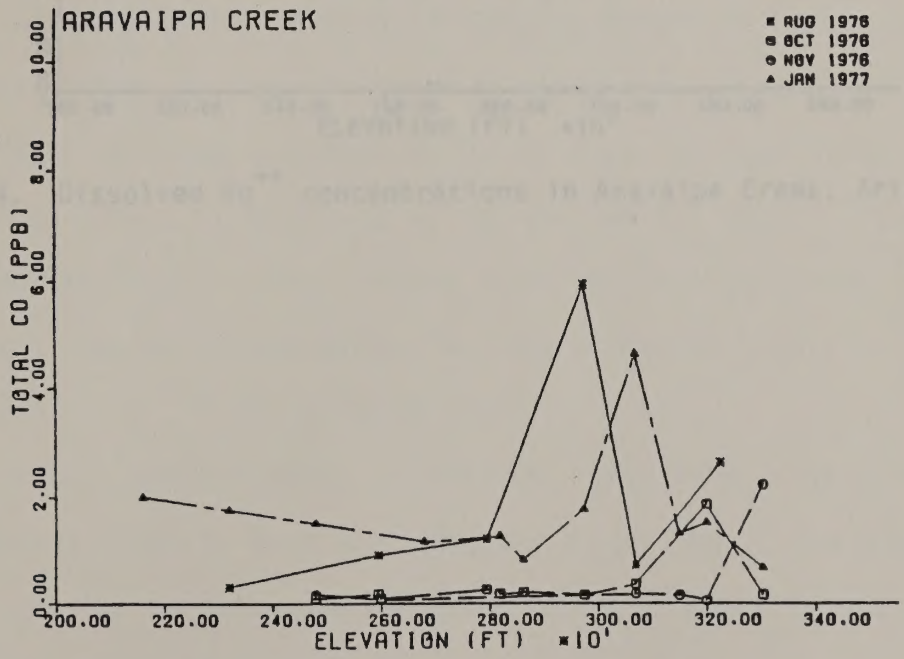

Figure V-23. Total Cd^{++} concentrations in Aravaipa Creek, Arizona.

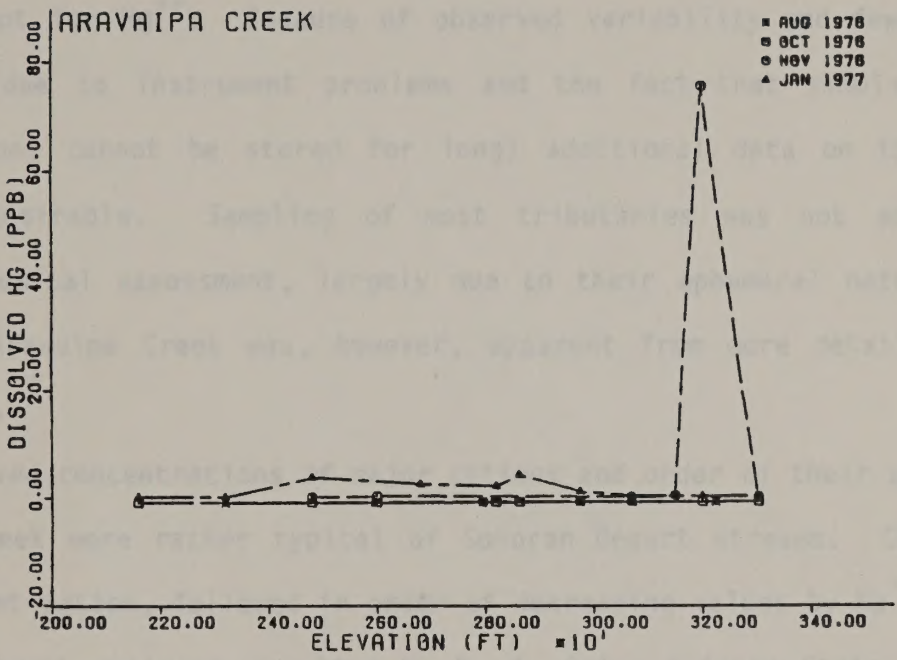

Figure V-24. Dissolved Hg^{++} concentrations in Aravaipa Creek, Arizona.

4. Summary and Discussion

Desert streams, with highly variable conditions of flow, pose significant problems in obtaining adequate samples over short periods of time. Sampling on Aravaipa Creek was sufficient for general assessment of the elements monitored, except for Hg^{++}. Because of observed variability and fewer analyses performed (due to instrument problems and the fact that samples for Hg^{++} determinations cannot be stored for long) additional data on that element would be desirable. Sampling of most tributaries was not adequate for specific chemical assessment, largely due to their ephemeral nature. Their impact on Aravaipa Creek was, however, apparent from more detailed data on that stream.

Dissolved concentrations of major cations and order of their abundance in Aravaipa Creek were rather typical of Sonoran Desert streams. Ca^{++} was the most abundant cation, followed in order of decreasing values by Na^+, Mg^{++}, and K^+. Additional analyses provided by G. A. Cole, Arizona State University, indicate major anions to be ranked as follows (mixed samples from mainstream stations, autumn 1976): HCO_3^-—229.2 mg/l, CO_3^{--}—112.8, SO_4^{--}—27.6, and Cl^-—7.5 mg/l. Water of the stream may therefore be classified as a dilute $Ca(HCO_3)_2$ water, with relatively great amounts of Na^+.

Total cation concentrations in Aravaipa Creek were slightly higher than dissolved levels (usually less than 10%) during periods of low discharge, but showed far greater maximum concentrations when elevated by ions associated with suspended sediments during spates.

On the basis of milliequivalent values of the three dominant cations, water of Aravaipa Creek and all tributaries studied excepting Horse Camp Canyon, grouped generally together. For these eight streams, Ca^{++} averaged

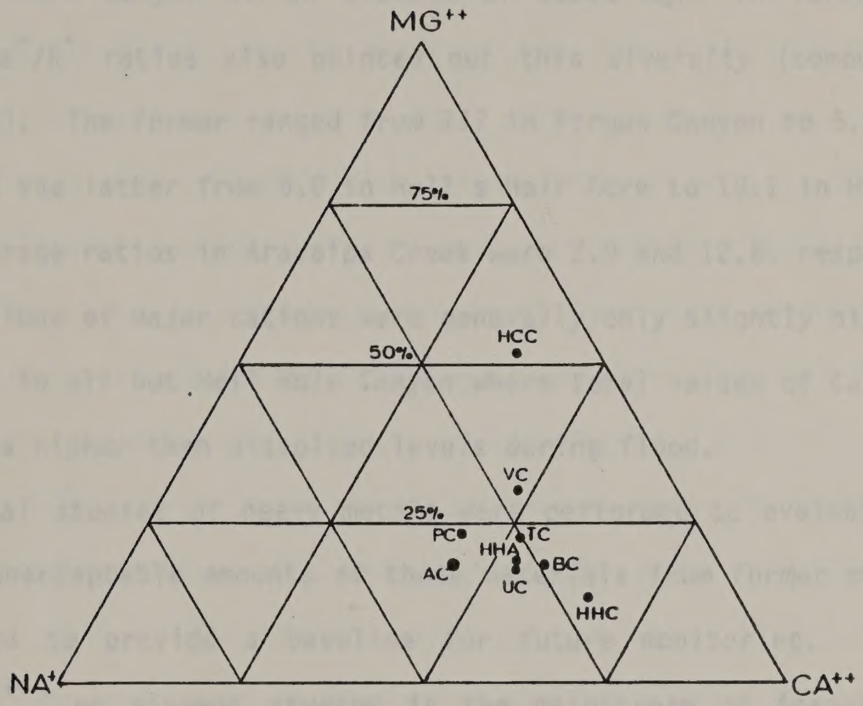

Figure V-25. Percentage distribution of major cations in waters of Aravaipa Creek and its tributaries, Arizona, based upon milliequivalents. Abbreviations: AC = Aravaipa Creek, HCC = Horse Camp Canyon, HHC = Hell Hole Canyon, BC = Booger Canyon, PC = Paisano Canyon, TC = Turkey Creek, UC = unnamed canyon, and VC = Virgus Canyon.

53% (44 to 61%), Na^+ 27% (21 to 36%), and Mg^{++} 20% (14 to 30%). Horse Camp Canyon had water that averaged about 51% Ca^{++}, 37% Mg^{++}, and only 12% Na^+ (Fig. V-25). Significant differences among tributaries were, however, apparent in their overall dissolved major cations, which ranged from 35.5 mg/l in Hell's Half Acre Canyon to an average of 108.5 mg/l in Turkey Creek. Ca^{++}/Mg^{++} and Na^+/K^+ ratios also pointed out this diversity (computed from milliequivalents). The former ranged from 117 in Virgus Canyon to 5.0 in Hell Hole Canyon, and the latter from 6.0 in Hell's Half Acre to 19.1 in Horse Camp Canyon. The average ratios in Aravaipa Creek were 2.9 and 12.8, respectively. Total concentrations of major cations were generally only slightly higher than dissolved values in all but Hell Hole Canyon where total values of Ca^{++} and K^+ were ca. 10 times higher than dissolved levels during flood.

Microchemical studies of heavy metals were performed to evaluate potential inputs of unacceptable amounts of those materials from former mine works (Appendix C) and to provide a baseline for future monitoring. With the exception of Hg^{++}, no element studied in the mainstream of Aravaipa Creek exceeded national or international water standards (Table V-10). Cd^{++} approached the maximum recommended concentrations for "sensitive" species of freshwater organisms.

Dissolved metals in tributaries for the most part also met recommended water standards; Cr^{+++}, Cu^{++}, Cd^{++}, and Pb^{++} were generally low and relatively stable in space and time. Mn^{++}, Fe^{++}, and Zn^{++}, however, were highly variable. Turkey Creek had Mn^{++} that regularly exceeded standards for domestic water supplies. The single sample from Bear Canyon had Fe^{++} that exceeded criteria both for aquatic life and domestic supplies, and water in Horse Camp Canyon exceeded the former standard in August. The unnamed tributary exceeded

recommended standards for Hg^{++} in domestic water supplies, and all tributaries sampled had more Hg^{++} than is recommended for aquatic organisms and for wildlife use.

Surface waters from tributary streams rarely had discernible effects on discharge of the mainstream of Aravaipa Creek. Most discharge of smaller canyons into Aravaipa Creek, except during flood, was subterranean through coarse sand/gravel/boulder substrates of their floods (see Section IV). Even smaller flash floods often infiltrated porous beds of washes and canyons before reaching channels of perennial streams (Cooperrider and Sykes 1938, Bruns and Minckley 1980). Substantial inputs of materials, usually finely-divided particulates and dissolved ones, may therefore happen without much surficial evidence, and must have occurred through Maroga Canyon into Aravaipa Creek in October 1976. A major convective storm was above the upper part of that canyon in mid-afternoon on the sampling date, and minor surface discharge was noted as was entry to the mainstream of gray-colored, milky water, discharging through deep gravels of Maroga Canyon's alluvial fan. Water upstream in Aravaipa Creek was clear, and samples taken farther downstream were collected prior to arrival of the input, thus "spikes" in concentration of a large number of dissolved and total analyses of various elements were recorded.

It is also possible that reducing conditions within sediments of washes may allow dissolution of materials that otherwise would have remained unavailable, further explaining the presence of locally high levels of some such materials.

Dissolved concentrations of heavy metals in Aravaipa Creek, compared with those in other streams of Arizona that are known to receive mine waste (e.g. Lyn and Mineral creeks), are quite low. The last two streams have from 100

to 1,000 times more Fe^{++}, Cu^{++}, Zn^{++}, and Mn^{++} than Aravaipa Creek (Follet and Wilson 1969, Rathbun 1975, 1975). Both streams, however, are in far closer proximity to mines than is Aravaipa Creek.

Concentrations of metals in Aravaipa Creek were furthermore more similar to control sites in two studies in Colorado (Wentz 1974, LaBounty et al. 1975), than they were to areas receiving inflow from mines. Waters receiving mine drainage in Colorado contained maximum concentrations of Cd^{++}, Cu^{++}, Pb^{++}, Fe^{++}, Mn^{++}, and Zn^{++} again 100 to 1,000 times greater than in Aravaipa Creek. Cr^{+++} was not detected in the Colorado studies, but was present in the Aravaipa.

It should again be noted that most heavy metals are required in miniscule amounts for life processes of organisms, and also brought out that standards proposed for "healthy" water supplies (Table V-10) may not universally apply. For example, threshold concentrations of lethality for some fishes of dissolved Fe^{++} is as low as 200 mg/l, and maximum recommended levels for Fe^{++} is as low as 200 mg/l, and maximum recommended levels for Fe^{++} in drinking water is 300 ug/l or 10.0 mg/l (US EPA 1973 and WHO 1971, respectively). Precipitation of Fe^{++} compounds also may cause consolidation of stream bottoms and eliminate benthic invertebrates and oxygenated interstices required by some fishes for incubation of ova. Permissible limits for Cu^{++} in water supplies is 1.0 mg/l (Table V-10), yet Lewis (1977) demonstrated the LC-50 (50% mortality of test animals) for Cu^{++} was 880 µg/l for longfin dace. A mixture of 210 µg/l Cu^{++} and 280 µg/l Zn^{++} was adequate to kill 50% of test fish in an allotted time, demonstrating the synergistic effects of some metals.

Aquatic plants also may be influenced by low concentrations of heavy metals. Algal photosynthesis has been reduced under experimental conditions

by dissolved Cu^{++} concentrations between 1.0 and 300 µg/l, and 10 µg/l Zn^{++} (Clendenning and North 1960, Steeman-Nielsen and Wium-Anderson 1971, Rabe et al. 1973), and NO_3-N fixation by algae was reduced by 5 to 10 µg/^{1} Cu^{++} (Horne and Goldman 1974). Photosynthesis and carbon assimilation by algae also have been reduced by Zn^{++} concentrations between 100 µg/l and 1.0 mg/l (Wissmar 1975, Goldman 1964).

Low maximum permissible levels of Hg^{++} (Table V-10) are because the element in its free state or as cinnibar (HgS) can be absorbed through skin and through gastrointestinal or respiratory tacts (USGS 1976). Fishes can live with no obvious adverse effects at levels of dissolved Hg^{++} far greater than those recommended (McKim et al. 1976), but concentrate the element through food chains from 3,000 to 10,000 times levels in water (Hannerz 1968), and therefore present problems at higher trophic levels, including man. Cd^{++} also is known to accumulate in vertebrates. Particulate materials that include Hg^{++}, Cd^{++}, and other heavy metals are ingested by filter-feeding organisms, thus accumulation sequences may be enhanced where total concentrations include a significant undissolved fraction.

Mean concentrations of total metals in Aravaipa Creek were in all instances substantially higher than dissolved levels (to 50 fold). Highest particle-bound loads were obviously associated with turbidity during floods, and may be attributable to mine seepage and exposed mine wastes in the watershed (Appendix C). Tributaries, with notable exceptions, were less extreme in total metals than the mainstream. However, this may be an artifact in part due to more comprehensive sampling of the channel. The major exception was Hell Hole Canyon, where total concentrations for Cr^{+++}, Cu^{++}, Cd^{++},

Fe^{++}, Mn^{++}, Pb^{++}, and Zn^{++}, were from 20 to more than 10,000 times dissolved levels during high discharge.

The significance of particle-associated heavy metals in natural waters has not been adequately assessed in the literature. Presence of elevated concentrations almost certainly indicates luxury concentration through local food webs into higher organisms. Sediment-bound elements are generally considered unavailable to plants, except under conditions of low pH and low dissolved oxygen where the ions may be released. This is unlikely in the Aravaipa Creek system, with relatively high pH and oxygen levels (Section V-B), but may occur within deeper sediments (see above). Diversity in the biota of Aravaipa Creek and its tributaries suggests that the potential influences of high particle-bound metal concentrations are not yet discernible.

B. Macrochemistry

1. Introduction and Methodology

Long-term (generally 24 hours or longer) studies of selected chemical features of Aravaipa Creek included analyses of dissolved oxygen concentrations, hydrogen ion levels (pH), conductance, and the macronutrients phosphate-phosphorus (PO_4-P) and nitrate-nitrogen (NO_3-N). Variations in these parameters were thus defined on a diel, seasonal, and annual basis, and at differing levels of discharge. The first three were determined electrometrically through use of a Hydrolab-11, Surveyor®, and macronutrients were analyzed colorimetrically with a Bausch and Lomb Mini-spectrometer®. Results were reproducible with both devices at approximately 95% levels of accuracy.

2. Dissolved Oxygen

Solubility of oxygen is considerably greater in cold than in warm water. The gas enters aqueous solutions by diffusion from air and through photosynthetic activities of algae and other plants, and when saturation is exceeded, diffusion gradients are reversed, especially in shallow, turbulent streams, and oxygen leaves the system. Oxygen removal from water is effected by respiration of the biota.

In Aravaipa Creek, levels of dissolved oxygen varied inversely to seasonal water temperatures, and in periods of high productivity varied positively with daytime light (Fig. V-26). Periods of low productivity, as after seasonal flooding and scour in winter and late summer, are indicated in the figure when nighttime oxygen concentrations exceeded those recorded in daylight hours.

In late winter and spring, prior to onset of summer flooding, daytime oxygen levels were significantly higher than those recorded at night. Photosynthetic activity of profuse stands of algae and diatoms produced oxygen supersaturations on many dates, despite turbulence in the system. Community respiration at night likewise lowered oxygen levels to substantially below saturation on occasion, although never to a level critical to the stream biota. Lowest levels of dissolved oxygen were recorded over a single 24-hour period in the upper segment and in the front wave of a flash flood on lower Aravaipa Creek.

Low oxygen in upper Aravaipa Creek in August 1977 was recorded five days after a flash flood. Algal populations prior to the spate were relatively high, but were deteriorating after a period of biomass accumulation and high productivity. The flood displaced algal mats to sides of the channel, buried

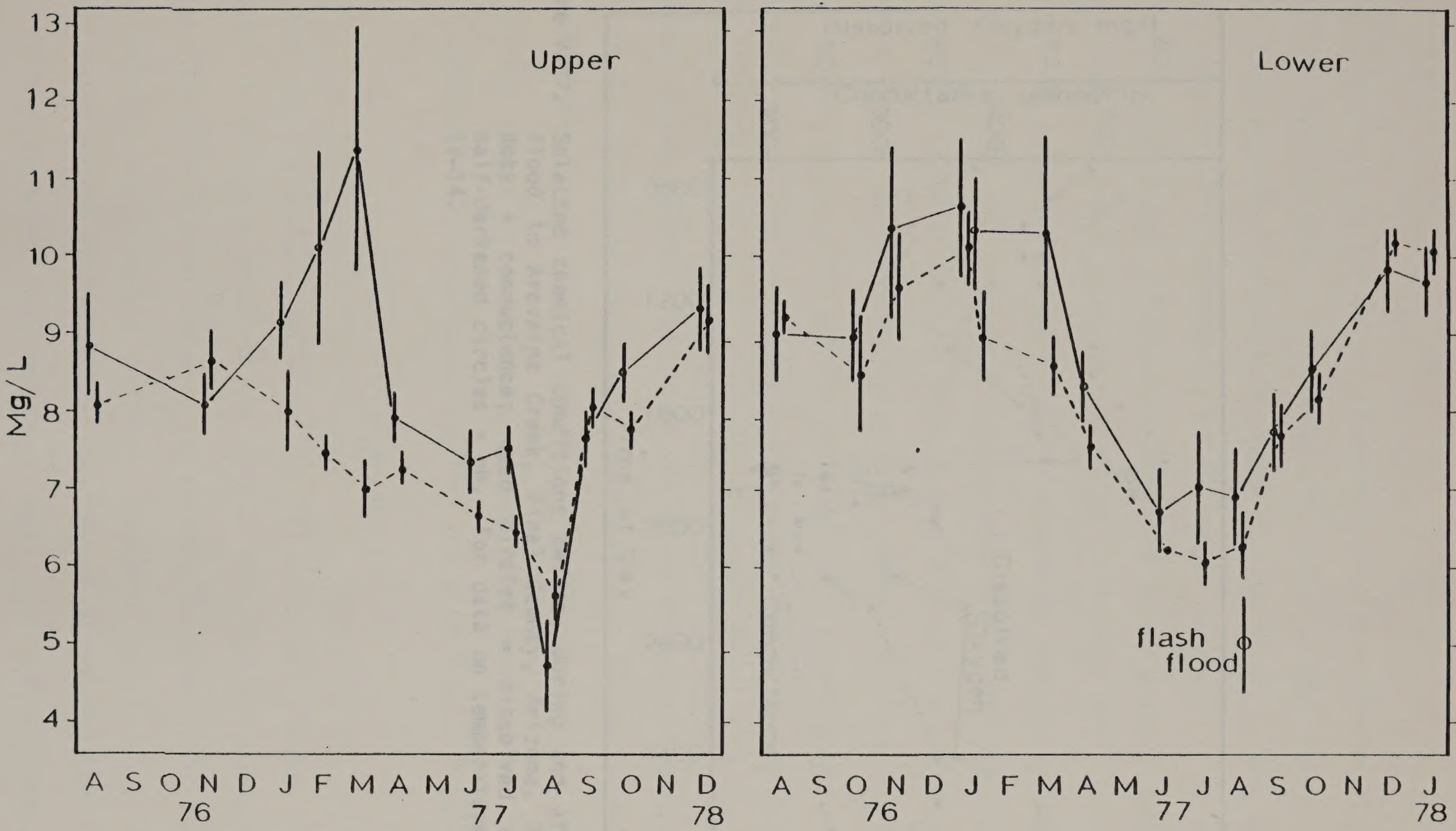

Figure V-26. Dissolved oxygen concentrations on various sampling dates at up- and downstream stations on Aravaipa Creek, Graham and Pinal counties, Arizona, 1976-78: Vertical bars indicate ranges over a 24-hour period; open circles are means for daylight hours; and dots are for means at night.

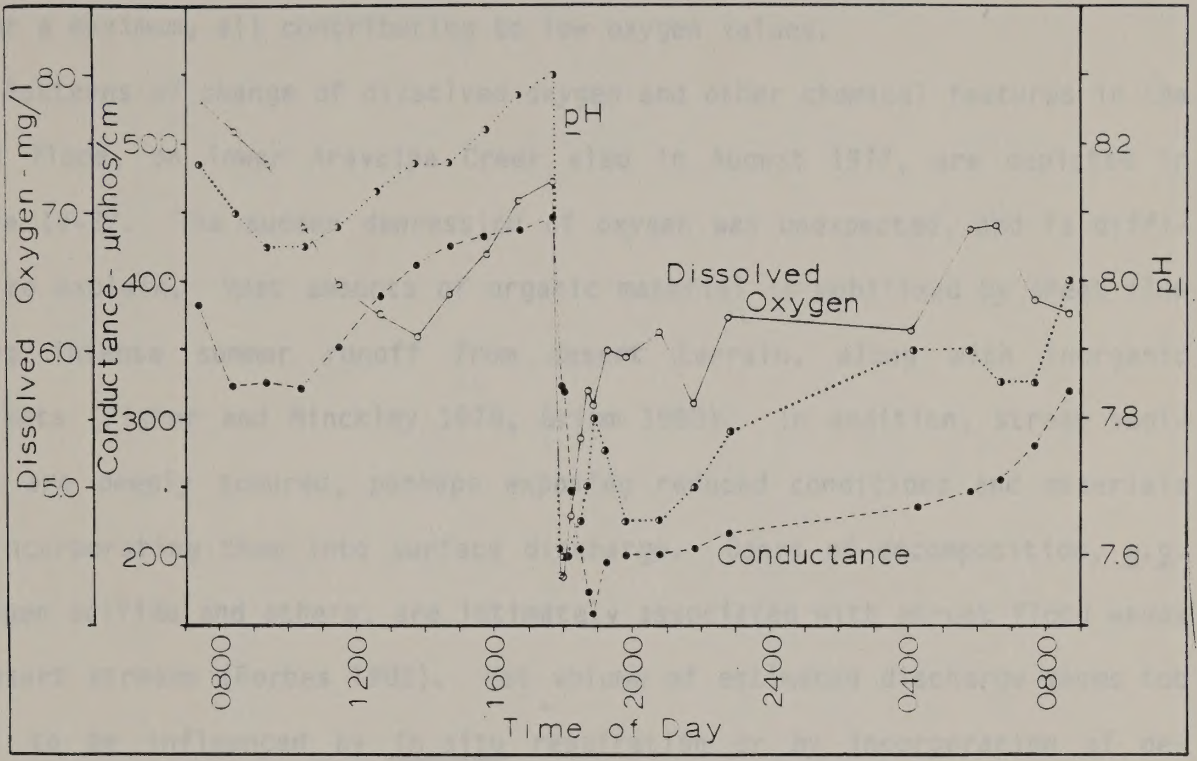

Figure V-27. Selected chemical conditions before, during and after a flash flood in Aravaipa Creek, Pinal County, Arizona, August 1977: dots = conductance; open circles = dissolved oxygen; and half-darkened circles = pH. For data on temperature see Figure IV-14.

some of them in sand, and caused accumulation of algal masses as large as 5.0 m^2 behind obstructions. Photosynthetic activity was therefore minimal, temperatures were high (Fig. IV-12, range 19.5 to 32.0^o C), and decomposition was at a maximum, all contributing to low oxygen values.

Patterns of change of dissolved oxygen and other chemical features in the flash flood, on lower Aravaipa Creek also in August 1977, are depicted in Figure IV-27. The sudden depression of oxygen was unexpected, and is difficult to explain. Vast amounts of organic material is mobilized by sheet flow during intense summer runoff from desert terrain, along with inorganic nutrients (Fisher and Minckley 1978, Grimm 1980). In addition, stream sediments are deeply scoured, perhaps exposing reduced conditions and materials and incorporating them into surface discharge. Odors of decomposition, e.g. hydrogen sulfide and others, are intimately associated with abrupt flood waves in Desert streams (Forbes 1902). Yet volume of estimated discharge seems too great to be influenced by in situ respiration or by incorporation of deoxygenated materials - discharge in the stream changed from an estimated 0.8 m^3/s to near 30.0 m^3/s in 17 minutes as the front wave passed. Further study of this phenomenon is obviously called for (see also Section VI-B).

3. Conductance

Specific conductance corrected to 25^o C ranged between 158 and 510 umhos/cm in Aravaipa Creek in the period 1976-78, with means for 24-hour studies generally falling between 430 and 460 umhos/cm (Fig. V-28). Since conductance is a reflection of total dissolved solids (TDS) in water, a general relationship exists between the two measurements despite variations resulting from different combinations of ions. For Aravaipa Creek, based upon

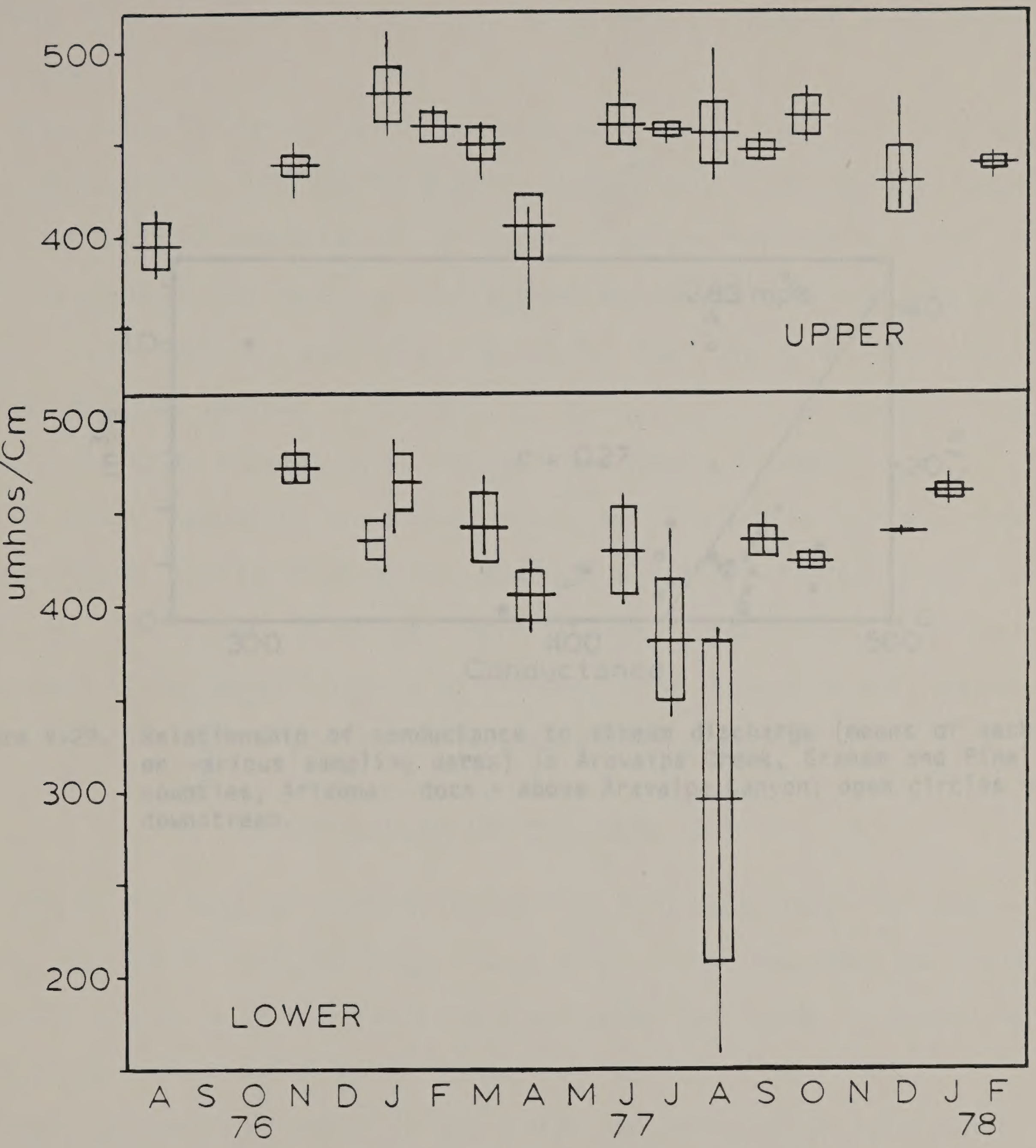

Figure V-28. Means (horizontal bar), ranges (vertical bar), and one standard error (rectangles) for conductance in Aravaipa Creek, Graham and Pinal counties, Arizona, 1976-1978. Numbers of samples range from 14 to 30 over 24- to 36-hour periods on each date

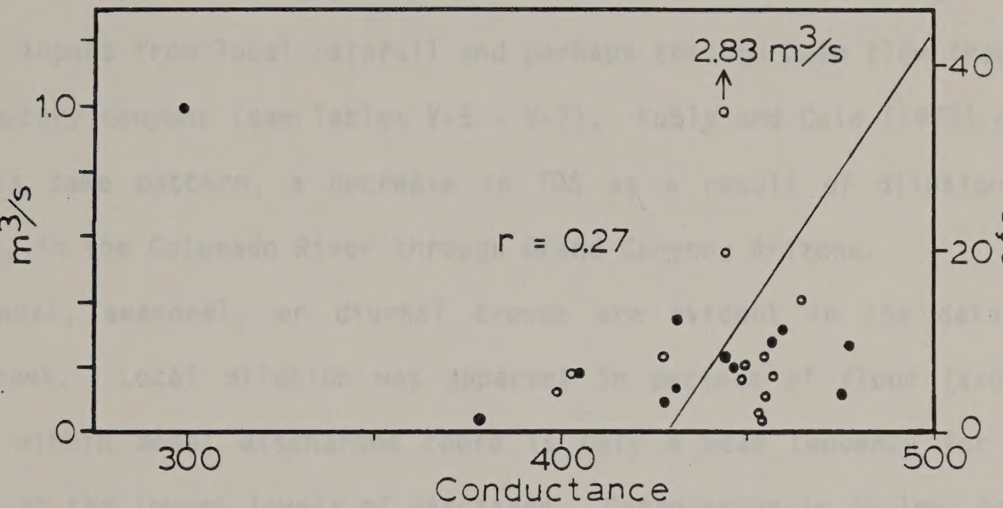

Figure V-29. Relationship of conductance to stream discharge (means of each on various sampling dates) in Aravaipa Creek, Graham and Pinal counties, Arizona: dots = above Aravaipa Canyon; open circles = downstream.

5 samples analysed for both parameters, conductance X 1.68±0.08 = TDS (range 1.53-1.74).

Grand means for paired sampling periods up- and downstream were 447.8 and 434.9 umhos/cm (TDS 752.3 and 730.6 mg/l), respectively, with the lower value downstream possibly reflecting precipitation of certain ions (see Fig. V-2) or more likely inputs from local rainfall and perhaps through base flow from more dilute tributary canyons (see Tables V-5 - V-7). Kubly and Cole (1979) demonstrated this same pattern, a decrease in TDS as a result of dilution from tributaries, in the Colorado River through Grand Canyon, Arizona.

No annual, seasonal, or diurnal trends are evident in the data from Aravaipa Creek. Local dilution was apparent in periods of flood (see Fig. V-27), but within modal discharges there is only a weak tendency for lower conductance at the lowest levels of discharge. Correlation is so low, however ($r = 0.27$), that such a relationship may only be suggested (Fig. V-29).

4. Hydrogen Ion Concentrations (pH)

Spatial and temporal patterns emerge from data on hydrogen ion concentration (as pH) in Aravaipa Creek (Table V-11) - the lowermost reach was invariably higher in pH (more alkaline), and values were lower in summertime and at night than in winter and during daylight hours.

Lower pH near the source of the stream may partially be explained by inflow of groundwater charged with carbon dioxide, and also by underflow in deep alluvium upstream from the canyon. Carbon dioxide in soils is derived from respiratory activities of bacteria, fungi, and other organisms, and when combined with water forms a weak solution of carbonic acid. Loss of carbon dioxide from the system through diffusion and photosynthesis by autotrophs

Table V-11. Frequency distribution of pH values on various sampling dates in Aravaipa Creek, Graham and Pinal counties, Arizona, 1976-78. Slashes (/) separate data from upper and lower parts of the stream.

Dates		Values							
		7.4-7.5	7.6-7.7	7.8-7.9	8.0-8.1	8.2-8.3	8.4-8.5	8.6-8.7	8.8-8.9
			Upper Aravaipa Creek				Lower Aravaipa Creek		
November 1976	Day	-	-	4	6	-	-	4	7
	Night	-	-	6	1	-	6	-	-
January 1977	Day	-	1	8	-	-	5	12	6
	Night	-	6	1	-	4	13	1	-
February	Day	-	4	5	-	-	- No data -		-
	Night	-	7	3	-	-	- No data -		-
March	Day	-	1	2	2	5/1	2	5	-
	Night	2	5	-	-	4	1	1	-
April	Day	-	1	9	1 /	1	2	7	-
	Night	-	7	1 /	2	4	2	-	-
June	Day	-	-	6	4 /	1	2	7	-
	Night	-	7	1 /	1	2	-	-	-
July	Day	-	1	5	5 /	2	8	-	-
	Night	-	7	2/5	3	1	-	-	-
August	Day	-	-	3	8/5	6	-	-	-
	Night	-	1/3	3/6	2/1	-	-	-	-
September	Day	-	-	-	4	4/1	9	-	-
	Night	-	-	-	8	1 /	6	-	-
October	Day	-	-	-	-	6	4 /	11	-
	Night	-	-	-	7	-	-	7	-

Table V-11. Concluded.

Dates		Values 7.4-7.5	7.6-7.7	7.8-7.9	8.0-8.1	8.2-8.3	8.4-8.5	8.6-8.7	8.8-8.9
			Upper Aravaipa Creek				Lower Aravaipa Creek		
December	Day	-	-	-	5	6	1/6	-	-
	Night	-	-	1	5	6	/ 6	-	1
January 1978	Day	-	- No data -		-	7	2	-	-
	Night	-	- No data -		-	10	-	-	-
February	Day	-	-	11	1	-	- No data -		-
	Night	-	-	7	-	-	- No data -		-

---

[1] Data from a flash-flood wave (Fig. V-28) on lower Aravaipa Creek were excluded.

results in an elevation of pH, and also may result in deposition of relatively insoluble salts such as calcium carbonate (see e.g. Fig V-2).

Inflow or underflow also would tend to suppress variations, as noted for temperatures in upper Aravaipa Creek, and pH variation was in fact less on an annual basis at the upper stations (Table V-11).

The tendency for decreased pH values throughout the system in summer may also be related to underflow. At low summer discharges, assuming a constant volume of water moving through pervious sediments of the stream bed, a larger proportion of total discharge might be beneath the surface of substrates at a given time and thus acquire and retain carbon dioxide from that source. Flood waters, generally excluded from Table V-11, tend to be less alkaline than those of the creek (Fig. V-27).

Day- and nighttime differences in pH may be attributed to photosynthetic activities of the stream's algal flora. Carbon dioxide is taken up during this process, forcing pH values upward, while biotic respiration at night adds the gas to water to lower pH. The greatest disparities between night- and daytime values in both stream reaches correspond well with maximum differences observed in dissolved oxygen data (compare Table V-11 and Fig. V-26).

5. Macronutrients

Nitrogen and phosphorus dynamics in low-desert streams in Arizona were recently studied in detail by Grimm (1980). Nitrogen is rare in desert soils, and its passage through stream systems involves a complex series of events which, in some instances, may result in its further depletion and resulting nitrogen limitation of primary production. Phosphorus cycles are less complex. Both macronutrients are influenced by biologic and non-biologic

processes in stream waters, but phosphorus seems far more available from physical sources, such as adsorbed to sediments, and rarely becomes depleted. Nitrogen and phosphorus are presumably taken up by algae at ratios equivalent to their concentrations in cell contents (ca. 1:14 in Cladophora sp.; Wong and Clark 1976, Grimm 1980), so nitrogen would theoretically be limiting to algal production when the ratio is less than that value, and phosphorus would be so when the ratio exceeds 14. Other nitrogen sources, e.g. ammonium, are relatively rare in streams of southeastern Arizona (Grimm 1980), and PO_4-P as orthophosphate is the form of that element directly available to plants.

Data for Aravaipa Creek indicate a relatively constant concentration of PO_4-P up- to downstream, before and after floods, and throughout the year (Fig. V-30, Table V-12). NO_3-N, on the other hand, was always lower downstream than in the upper reaches when paired sampling periods were compared, was higher after periods of flooding throughout the system, and was lower after periods of low flow when relatively high primary productivity was occurring in both upper and lower reaches (but more spectacularly so after low discharge periods at the lowermost end; Table V-13). Reduction in NO_3-N up- to downstream in paired sampling periods after low flow averaged about 52%, whereas the same value following flooding was about 31%. Ratios of NO_3-N:PO_4-P, a rough measure of actual nitrogen:phosphorus ratios, never exceeded 10 in flowing segments of upper Aravaipa Creek, or 5 in the lowermost section, so nitrogen would be the limiting nutrient under conditions of short supply.

Examination of long-term sampling data revealed no statistically significant differences among data collected during the day and those from nighttime hours. Logically, at least NO_3-N should be lower during daylight hours as a result of algal uptake, but variation was high, masking any differences that

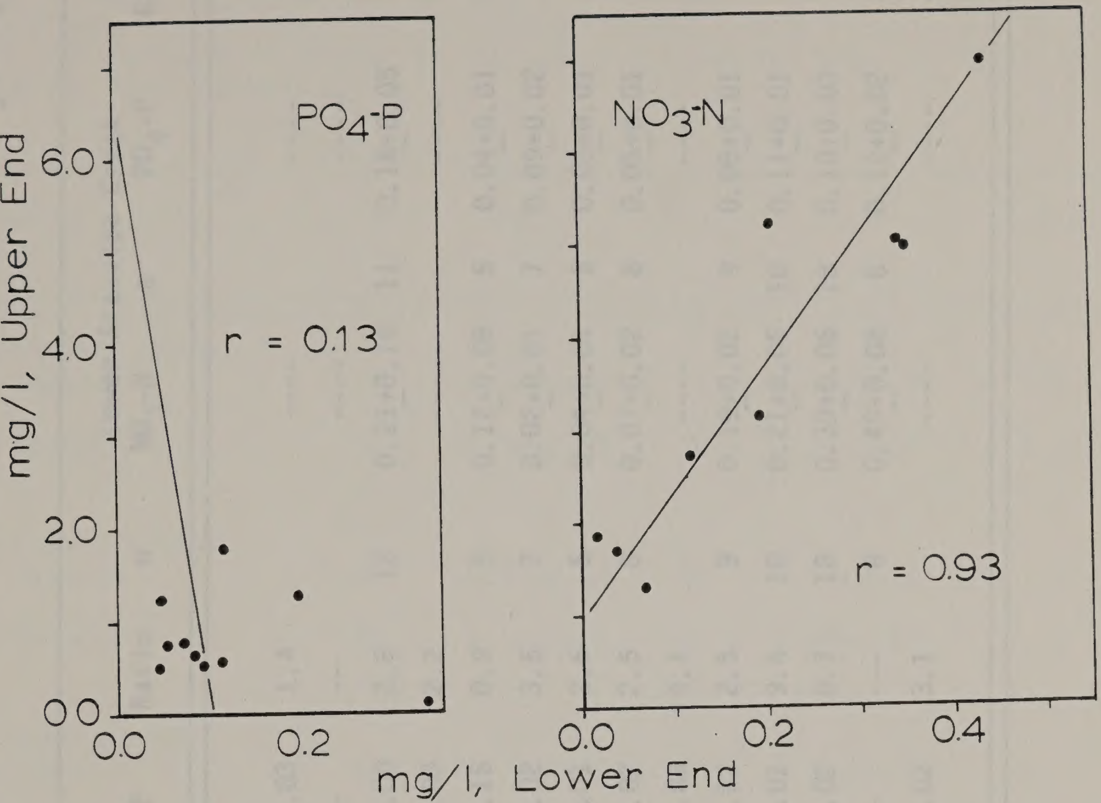

Figure V-30. Relationships of concentrations of PO_4-P and NO_3-N at upper and lower stations on Aravaipa Creek, Graham and Pinal counties, Arizona, 1976-78. Data are daily means for paired up- and downstream sampling dates; see text for further explanation.

Table V-12. Mean concentrations of macronutrients in upper and lower Aravaipa Creek, Graham and Pinal counties, Arizona, 1976-78. Sample series marked with an asterisk (*) were taken within 30 days following flooding; see text for further explanation. Data in mg/l±one standard error of the mean; n = number of samples over a 24-hour period; and ratios are for NO_3-N:PO_4-P.

		Upper Aravaipa Creek					Lower Aravaipa Creek			
Dates	n	NO_3-N	n	PO_4-P	Ratio	n	NO_3-N	n	PO_4-P	Ratio
August 1976	9	0.14±0.11	9	0.10±0.03	1.4		----		----	---
November		----		----	---		----		----	---
January 1977	5	0.51±0.06	3	0.18±0.00	2.8	12	0.21±0.16	11	0.16±0.05	1.3
February	4	0.43±0.08	4	0.20±0.03	2.2		-----		----	---
March	8	0.28±0.15	8	0.34±0.15	0.9	5	0.12±0.08	5	0.04±0.01	3.0
April	7	0.19±0.02	7	0.05±0.02	3.6	7	0.02±0.01	7	0.09±0.02	0.2
June	7	0.17±0.06	7	0.06±0.01	2.6	5	0.04±0.01	5	0.08±0.01	0.5
July	8	0.13±0.02	8	0.05±0.02	2.5	8	0.07±0.02	8	0.05±0.01	1.5
August*	10	0.56±0.12	10	0.14±0.03	4.1		----		----	---
September*	11	0.31±0.11	11	0.12±0.02	2.5	9	0.19±0.02	9	0.05±0.01	0.4
October*	10	0.53±0.13	10	0.06±0.01	9.4	10	0.21±0.06	10	0.11±0.01	0.6
December*	17	0.61±0.12	17	0.07±0.02	8.7	18	0.39±0.06	18	0.10±0.03	3.9
January 1978*		----		----	---	8	0.49±0.08	8	0.12±0.02	4.0
February*	8	0.32±0.11	8	0.10±0.02	3.1		----		----	----

Table V-13. Summary of macronutrient concentrations after various periods of flood or drought, and as paired sampling periods, up- and downstream in Aravaipa Creek, Graham and Pinal counties, Arizona. Data in mg/l±one standard error of the mean; n = number of samples; and ratios are for NO_3-N:PO_4-P. Data compiled from Table V-12.

Conditions or Data Sets	n	NO_3-M	n	PO_4-P	Ratios
Paired Sampling Dates					
Upper Segment	73	0.40±0.19	71	0.11±0.09	3.6
Lower Segment	74	0.20±0.09	73	0.09±0.04	2.2
After Drought Periods					
Upper Segment	48	0.27±0.06	46	0.14±0.10	1.9
Lower Segment	37	0.13±0.13	36	0.08±0.04	1.6
After Flood Periods					
Upper Segment	56	0.49±0.15	56	0.09±0.04	5.4
Lower Segment	45	0.34±0.13	45	0.09±0.03	3.7

might have existed, and differences that occurred at a given sampling point were apparently small enough to fall outside the range of sensitivity of analytical techniques.

Water sources for Aravaipa Creek, where flow originated from the substrate, had about the same levels of PO_4-P as samples from the flowing stream, but NO_3-N levels were invariably higher in such places. Uptake of NO_3-N below such sources is rapid, positively correlated with initial concentrations, and obviously related to standing crops and primary productivity of algae (Grimm 1980; see also Section VI-A). Data for uptake of NO_3-N below the source of Aravaipa Creek and in Turkey Creek are in Table V-14.

Flood waters also were high in NO_3-N, sometimes spectacularly so when front waves of flash floods were sampled. A spate of about 0.9 m^3/s in Hell Hole Canyon in August 1976 had 68.5 mg/l NO_3-N and 1.06 mg/l PO_4-P. A small flood of about 1.58 m^3/s in Aravaipa Creek near the mouth of Turkey Creek that same month carried 19.6 mg/l NO_3-N; PO_4-P was not determined. A flood of ca. 30#m^3/s near the mouth of Aravaipa Creek in August 1977 yielded an average of 42.16±16.85 mg/l NO_3-N (range 28.4-61.3 in five samples taken over a 10-minute period). PO_4-P in the same samples averaged only 0.49±0.32 mg/l (range 0.3-1.0). Fisher and Minckley (1978) and Grimm (1980) reported similarly high values for NO_3-N in floods of other low-elevation watercourses in Arizona.

Table V-14. Up- to downstream changes in macronutrients in Aravaipa and Turkey creeks, Graham County, Arizona. Sample series marked with an asterisk (*) were taken within 30 days of flooding; see text for further explanation. Data in mg/l.

Dates	Source	100 m	500 m	1,000 m	2,500 m
			Aravaipa Creek, NO_3-N		
August 1976	0.47	0.37	No data	0.24	0.09
October	0.51	0.21	0.20	0.18	0.11
January 1977	0.74	0.63	0.40	0.39	0.38
June	0.39	0.41	0.21	0.09	0.11
October*	0.94	0.88	0.83	0.72	0.73
December*	1.07	0.93	0.97	0.83	0.85
January 1978*	1.31	0.94	0.91	0.93	0.95
			Turkey Creek, NO^3-N		
October 1976	0.64	0.29	0.07	not detected	not detected
			Aravaipa Creek, PO_4-P		
August 1976	0.07	0.06	0.07	0.05	0.06
October	0.11	0.09	0.09	0.08	0.08
November	0.11	0.09	0.10	0.09	0.12
January 1977	0.16	0.16	0.14	0.16	0.15
June	0.08	0.09	0.09	0.07	No data
October*	0.17	0.16	0.17	0.21	0.17
January 1978*	0.21	0.22	0.19	0.18	0.21
			Turkey Creek, PO_4-P		
October 1976	0.11	0.14	0.11	0.10	0.11
January 1977*	0.10	0.10	0.09	0.08	0.10

VI. BIOLOGICAL INVESTIGATIONS

A. Algae and Algal Pigments

1. Introduction

Algae form the basis for productivity of most aquatic systems. In southwestern streams, in situ fixation of carbon through photosynthesis provides a majority of the organic materials upon which higher organisms depend (Minshall 1978), and production rates are such that remarkably high standing crops are present (Busch and Fisher 1981, Gray 1980). In flowing waters, most algae colonize substrates - sediments, rocks, debris, and other living organisms - and are termed periphyton (Wetzel and Westlake 1969). Appropriate adjectives (e.g. epilithic, for algae living on stones; epiphytic, for those on other plants; and epipelic, for algae living on the surfaces of finer sediments) are used to specify habit and habitats.

Most algal communities in Aravaipa Creek were dominated by diatoms (Bacillariophyceae) and green algae (Chlorophytae) on stabilized substrates in current. A number of other groups were present in special places such as floodpools, small backwaters, and quiet habitat in the mouths of side canyons. A list of taxa identified from the system is in Table VI-I.

2. Methodology

Sampling of algal populations for quantitative estimation of biomass and standing crops is remarkably difficult. Direct enumeration and determination of biomasses could not be done because of time constraints, plus other

Table VI-I. Algal genera identified from Aravaipa Creek, Graham and Pinal counties, Arizona.

CHLOROPHYTA

Ankistrodesmus
Chlamydomonas
Chlorococcum
Cladophora
Coelastrum
Gongrosira
Hydrodictyon
Microspora
Mougeotia
Oedogonium
Pediastrum
Rhizoclonium
Scenedesmus
Spirogyra
Stigeoclonium
Tetraspora
Ulothrix
Zygnema

CHAROPHYTA

Chara

CYANOPHYTA

Anabaena
Cylindrocapsa
Gleocapsa
Lyngbya
Nostoc
Oscillatoria
Sprulina

EUGLENOPHYTA

Euglena
Phacus

CHRYSOPHYTA

Vaucheria
Achnanthes
Amphora
Caloneis
Cocconeis
Cyclotella
Cymbella
Denticula
Diatoma
Fragilaria
Gomphonema
Hautzschia
Melosira
Meridion
Navicula
Nitzschia
Pinnularia
Rhopaloda
Surirella
Synedra

sampling difficulties (see Wetzel and Westlake 1969). Determination of photosynthetic pigment concentrations was thus settled upon as an indirect measure of populations. Problems still exist, however, especially those involving chlorophyll degradation productions (phaeophytins) that may interfere with spectrophotometric analyses. Corrections for possible phaeophytins were not applied to samples. These products are most abundant in later stages of development of algal communities, as successive algae colonize and die, so highest values are most suspect. This is especially true after long periods of low discharge that allowed accumulation of dense mats. Mineral substrates in Aravaipa Creek add another difficulty, making removal of algal cells difficult so that complete extraction of chlorophyll might not occur; underestimation of standing crops may result.

Algae tend to be distributed in patches, especially when colonizing a reach of stream after flood (Busch 1979), and this also causes sampling problems. To circumvent this, three types of samples were taken for determination of chlorophyll a: (1) A suction device was utilized to obtain interstitial and fragmentary materials from about 50 cm^2 of bottom--particulate materials were removed from water by filtration through HA® Millipore filter discs (pore size 0.45 u), which were placed on ice and returned to the laboratory; (2) a scoop of substrate, approximately 1.0 cm deep, 10 cm wide, and 10-20 cm long, was taken, gently washed free of particles, then iced; and (3) a composite scoop of bottom materials was taken as above, and treated the same except it was not washed to remove interstitial materials. Sampling was done in current, near shore, and in the center of the channel at each study site.

In the laboratory, extraction of chlorophyll a was by 95% acetone in dark, cool surroundings for 20 hours. Samples were treated with magnesium carbonate to retard chlorophyll degradation, filtered, and analyzed at 665 um, with a correction for residual turbidity at 750 um, on a Bausch and Lomb Mini-spectrometer. Approximation of chlorophyll a was made by use of formulas provided by Talling and Driver (1963). Conversion of these values to organic weight was made by multiplying by 90, assuming that populations in Aravaipa Creek were rarely nutrient limited and that carbon is 50% of organic weight (see Strickland 1960).

Chlorophyll a determinations from mats of Cladophora glomerata, the dominant large alga in the creek, were so variable that such sampling, was terminated after a few study periods. For example, five replicates from a single mat near Turkey Creek varied so that one standard error of the mean was greater than the mean - 267.9±292.8 mg/m^2 chlorophyll a (range 61.4 - 873.9), resulting in an estimate of 24.1±31.6 g/m^2 ash-free dry weight. Actual weights of the alga were far less variable, 25.7±7.6 g/m^2. This resulted from the community being heterogenous in time and space - some sections were growing actively, some were senescent, and the large alga is inhabited by a myriad of epiphytes that also influence results. Samples of C. glomerata were therefore taken directly, air dried, and weighed after firing at 550° C for 4 hours to estimate standing crops.

Analyses for pigments other than chlorophyll a were inconsistent and are not presented.

3. Results

Interstitial or otherwise unattached (epipelic) algae estimated from chlorophyll *a* in 118 samples from Aravaipa Creek prior to onset of sustained flooding in July 1977 averaged about 0.153 g/m^2, 10.8% of the total estimated standing crop. Samples from the same period that were washed of epipelic materials, therefore representing epilithic components of the community, and those including a composite of algal types (epipelic ± epilithic), differed by about the same percentage (1.233 *versus* 1.422 g/m^2, respectively). Washed samples were therefore arbitrarily increased by 10.8% and combined with total samples for presentation (Table VI-2). Encrusting communities consisted almost entirely of diatoms.

Data on standing crops of larger filamentous algae (*Cladophora glomerata* + epiphytes) in bottom samples from Aravaipa Creek were presented by Bruns and Minckley (1980) for the period April 1975 through April 1976, and these were supplemented by additional, although less extensive sampling, through April 1978 (Table VI-3).

Standing crops of periphyton in streams are related to light intensity, temperature, and scour, and to more subtle things as grazing by consumers, possible nutrient limitations, and senescence. Comparisons of up- and downstream values of standing crops of algae with those from within Aravaipa Canyon revealed significant differences obviously commensurate with lower light intensity in the narrow gorge. The first two means for encrusting forms (Table VI-2) are essentially the same, 1.475 and 1.618, respectively (grand mean 1.580 g/m^2), whereas the average within the canyon was 0.490 g/m^2. The large, filamentous *C. glomerata* community averaged 11.0 times higher in standing crop than estimates for encrusting periphyton above the canyon, only

Table VI-2. Standing crops of encrusting periphyton derived from determinations of chlorophyll *a* (X 90) within and upon (epipelic) and attached (epilithic) to substrates in Aravaipa Creek, Graham and Pinal counties, Arizona. Data are ash-free dry weights, g/m^2; numbers of samples are in parentheses.

Dates	Upper		Canyon		Lower	
	epipelic	epilithic	epipelic	epilithic	epipelic	epilithic
September 1976	0.117	0.131	0.036	0.076	0.072	0.638
	(18)	(25)	(5)	(8)	(5)	(14)
October	0.306	2.522	0.333	0.847	0.441	3.598
	(7)	(19)	(4)	(8)	(6)	(16)
November	0.234	0.999	-----	-----	0.045	1.904
	(8)	(20)			(6)	(12)
January 1977	0.405	2.655	0.009	0.143	0.009	0.133
	(11)	(19)	(2)	(5)	(4)	(8)
February	0.009	2.789	-----	-----	0.018	1.504
	(3)	(12)			(8)	(29)
March	0.018	0.742	0.000	0.447	0.000	0.571
	(6)	(12)	(5)	(10)	(2)	(6)
April	0.000	1.228	-----	-----	0.000	1.247
	(3)	(6)			(4)	(8)
June	0.441	1.418	-----	-----	0.000	1.552
	(3)	(9)			(1)	(9)
July[1]	0.072	0.923	-----	-----	0.000	0.999
	(4)	(8)			(3)	(6)
July[1] through April 1978	0.009	0.029	0.009	0.038	0.009	0.038
	(24)	(61)	(11)	(23)	(16)	(52)
Means, paired samples only	0.207	1.475	0.099	0.409	0.180	1.618
	(42)	(75)	(16)	(31)	(17)	(44)
	0.197	1.285	-----	-----	0.090	1.551
	(63)	(130)			(39)	(108)

---

[1] Before and after dates in July when sustained flooding commenced.

Table VI-3. Standing crops of filamentous algae (Cladophora glomerata + epiphytes) in samples from Aravaipa Creek, Graham and Pinal counties, Arizona. Data are ash-free dry weights, g/m^2; numbers of samples are in parentheses.

Dates	Upper	Canyon	Lower
April 1975	41.9 (5)	5.4 (6)	6.5 (4)
June	19.4 (5)	5.4 (6)	20.5 (4)
September	5.4 (5)	0.0 (6)	1.1 (4)
October	3.2 (5)	0.0 (6)	5.4 (4)
December	3.2 (5)	Tr. (6)[1]	52.7 (4)
January-February 1976	15.1 (5)	5.4 (6)	84.0 (4)
March	11.8 (5)	3.2 (6)	28.0 (4)
April	4.3 (5)	6.5 (6)	14.0 (4)
September	4.8 (2)	0.7 (2)	5.1 (4)
October	9.3 (3)	1.4 (2)	16.9 (4)
November	10.1 (4)	---	23.7 (4)
January 1977	26.7 (4)	4.9 (2)	38.7 (4)
March	36.5 (4)	11.1 (1)	43.7 (4)
June	41.0 (2)	---	38.4 (2)
July[2]	34.8 (4)	---	56.7 (2)
July[2] through April 1978	0.3 (9)	---	0.1 (9)
Means, paired samples only	15.3 (53)	3.2 (55)	26.4 (48)
	15.4 (72)	---	23.5 (65)

---

[1] Tr. = less than 0.05 g/m^2.

[2] Before and after dates in July when sustained flooding commenced.

7.8 times higher within the gorge, and 17.0 times higher in the lower reach (Table VI-3). The alga requires relatively high light intensity (Warren et al. 1960), as well demonstrated, and was far less abundant even in places where the stream was shaded by riparian trees (Bruns and Minckley 1980).

Cladophora glomerata has been reported to be inhibited by termperatures higher than 25^{0} C in Michigan Streams (Blum 1956, 1960). Its occurrence and distribution in Aravaipa Creek, and elsewhere in Arizona, obviously involves temperature tolerances higher than that in summer, but the alga did appear to become less abundant in that period on the basis of qualitative observations. No such relationships were obvious in quantitative data. No alga identified from Aravaipa Creek was considered characteristic of thermal environments (see Brock 1970).

No algae resist scour, as was obvious in information derived both from chlorophyll a and direct weights of periphyton in Aravaipa Creek. This physical factor was superimposed on all other obvious features regulating algal populations. After flooding commenced in July 1977 (Fig. VI-1), algae were essentially absent from the system. Relationships of biomass to discharge are apparent when one compares length of time of modal discharge prior to a given sampling period with biomasses recovered (Fig. VI-2). In no instance did samples within 15 days following a spate yield more than 0.5 g/m^2 of epilithic algae or more than 6.0 g/m^2 of Cladophora, whereas with increasing time after flood, ever-greater biomasses of both components was obvious.

The encrusting (epilithic + epipelic) community recovered quickly from disruption, increasing its mean biomass by ca. 43 times in the first 30 days above the canyon and 21 times in the downstream reach. Increase in the canyon was 18 times, reflecting shading far less than expected. The community

7.2 times higher within the gorge, and 17.0 times higher in the lower reach (Table VI-2). The alga requires relatively high light intensity (Warren *et al.* 1960), as well demonstrated, and was far less abundant even in places where the stream was shaded by riparian trees (Bruns and Minckley 1980).

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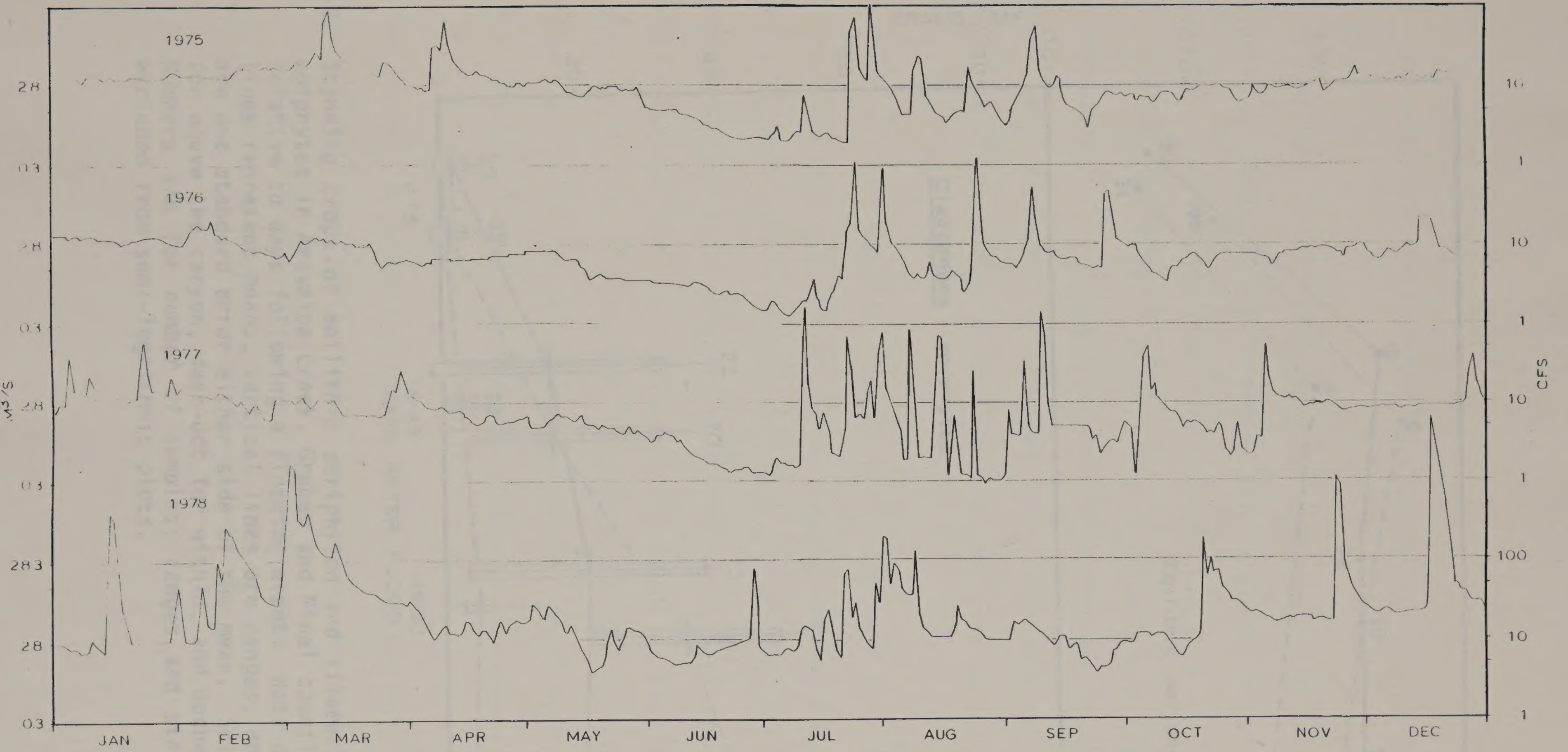

Figure VI-1. Mean daily discharge of Aravaipa Creek, Pinal County, Arizona, 1975-78, compiled from U.S. Geological Survey records (published periodically and unpublished).

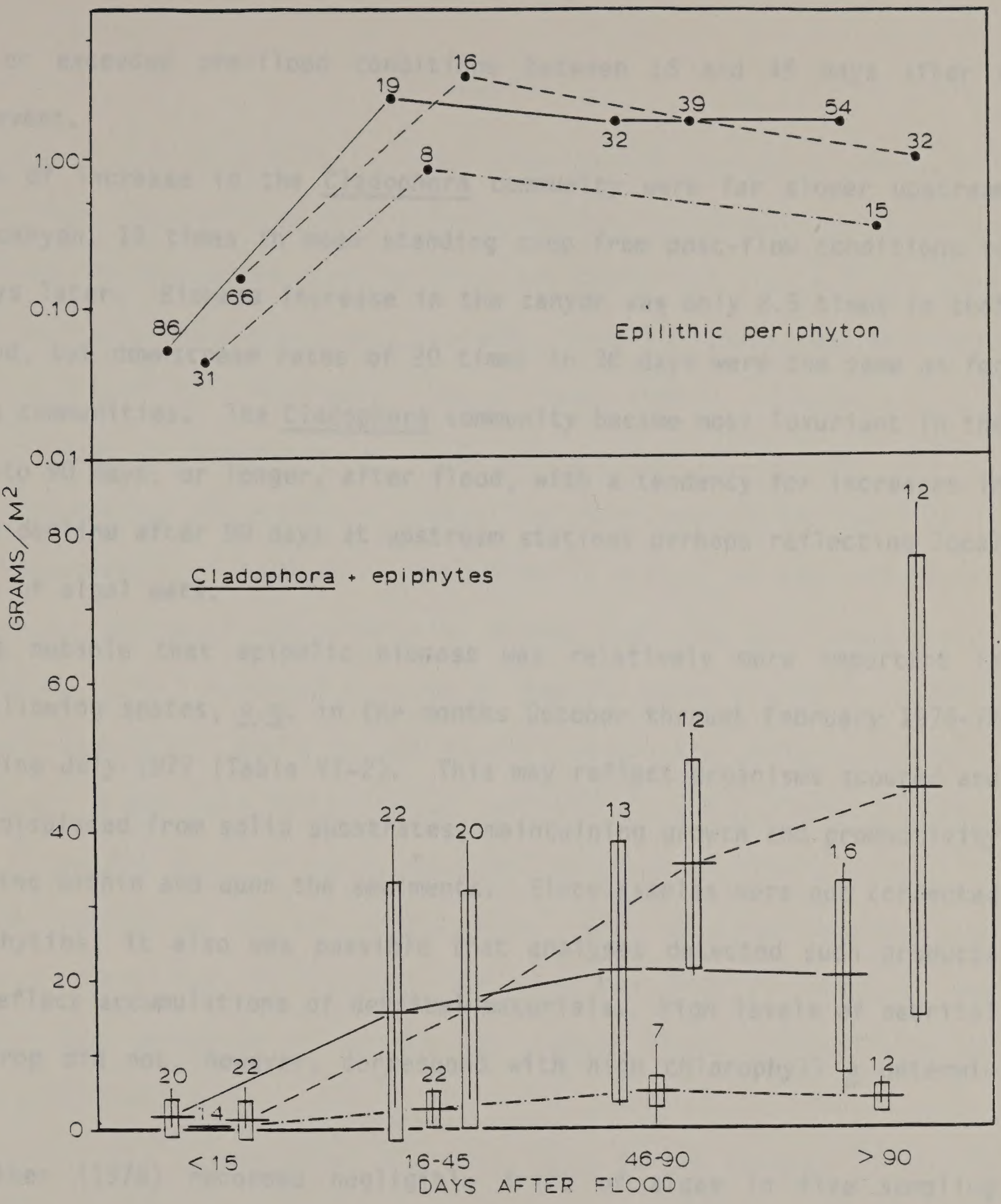

Figure VI-2. Standing crops of epilithic periphyton and filamentous algae + epiphytes in Aravaipa Creek, Graham and Pinal counties, Arizona, relative to days following a flooding event: dots or horizontal lines represent means, vertical lines are ranges, and rectangles are one standard error either side of the mean. Solid lines are for above the canyon, dash-dot for within, and dashed for below. Numbers are for number of samples; ranges and standard errors excluded from semi-logrithmic plots.

attained or exceeded pre-flood conditions between 16 and 45 days after a flooding event.

Rates of increase in the Cladophora community were far slower upstream from the canyon, 15 times in mean standing crop from post-flow conditions to ca. 30 days later. Biomass increase in the canyon was only 8.5 times in that same period, but downstream rates of 20 times in 30 days were the same as for encrusting communities. The Cladophora community became most luxuriant in the period 45 to 90 days, or longer, after flood, with a tendency for increases in biomass to decline after 90 days at upstream stations perhaps reflecting local senescence of algal mats.

It is notable that epipelic biomass was relatively more important in periods following spates, e.g. in the months October through February 1976-77 and following July 1977 (Table VI-2). This may reflect organisms scoured and otherwise displaced from solid substrates, maintaining growth and productivity by colonizing within and upon the sediments. Since samples were not corrected for phaeophytins, it also was possible that analyses detected such products and thus reflect accumulations of detrital materials. High levels of detrital standing crop did not, however, correspond with high chlorophyll a determinations.

Schreiber (1978) recorded negligible drift of algae in five sampling periods at a station near Turkey Creek. Only in January 1976 was a value higher than "trace" recorded, 301.4 mg/m^3 (wet weight = ca. 0.02 g/m^3, ash-free dry weight). Far greater drift was noted on other occasions, but unfortunately was not sampled.

4. Discussion

Standing crops of periphyton in Aravaipa Creek during periods of modal discharge were high, generally exceeding those records for streams in temperate regions. Some representative standing crops are means of 2.5 to 5.0 g/m^2 over a 20-month period in Morgan's Creek, Kentucky (Minshall 1968), and an annual average of 10.0 g/m^2 in Berry Creek, Oregon (Reese 1966). McIntire's (1973) laboratory streams in Oregon yielded means ranging from 15.6 to 65.7 g/m^2 of mixed periphyton after six months of stable flow under controlled conditions.

Most measurements of biomass of periphyton in natural stream communities in the American Southwest approximate or exceed even the last experimental values. Naiman (1974) reported a range of monthly means of 118.7 to 295.9 g/m^2 (annual mean 163.2 g/m^2) in the stable, remarkably productive Tecopa Bore, a thermal stream near Death Valley, California. Grimm (1980) similarly found _ca_. 50 to 300 g/m^2 in small, unshaded sections of desert streams in Arizona after varying periods of low discharge. Aravaipa Creek thus had high mean standing crops that corresponded well to data from elsewhere in the region, with the exception of within its canyon where shading effected suppression of productivity.

Recovery of the system after flooding, in a period between 16 and 45 days, compares remarkably well with demonstrated recovery of streams of the Sycamore Creek watershed, central Arizona (Gray 1980). In that system, most algal communities recovered within 5 weeks (35 days) after scour.

B. Detrital Materials

1. Introduction and Methodology

Detrital materials in streams are often considered the principal food base for invertebrates, and thus for consumers at higher levels (Hynes 1961, *et seq.*). In heavily vegetated zones, autumn-shed leaves and other parts of deciduous trees are major inputs of organic materials (Teal 1957, Hall 1972, Fisher and Likins 1973). Most desert streams, however, have relatively barren watersheds, plus organic transport from land surfaces is restricted to limited and rare occurrences of rainfall adequate to create sheet flow. Leaf fall from broadleafed deciduous riparian trees along Aravaipa Creek occurs in December (Bruns and Minckley 1980), but large accumulations rarely are present.

Detrital materials in the channel consist of both allochthonous and autochonous debris, and were sampled along with the *C. glomerata* community just discussed. Samples were air elutriated through 203 um mesh netting, dried, then fired at 550^{o} for 4 hours to determine ash-free dry weight. Estimates are minimal since a large proportion of organic material in desert streams is less than 100 um (> 90%; Gray 1980), and must have passed through the netting. Some information was obtained on drifting (exported) detritus by Schreiber (1978). Data on drifting detrial materials were originally presented as wet weight, and were converted to approximate ash-free dry weight by multiplication by 0.05.

2. Results

Detritus was most abundant in Aravaipa Creek after flooding, and most of it was identifiable at those times as finely ground or fragmented leaves, stems, and twigs of terrestrial plants. Amounts after floods were comparable to, or exceeded, standing crops of periphyton after periods of low flow (compare Tables VI-3 and VI-4). Mean amounts of detrital material ranged from 25.8 to 47.0 g/m^2 in the creek immediately following spates, and from 1.66 to 7.14 g/m^2 after 45 or more days of modal discharge. Gray (1980) produced similar data on diminution of allochthonous debris in Sycamore Creek, Arizona. His values, including all particulate organic materials, were 231.6 g/m^2 within 15 days after flooding, 75.7 in the period 16-45 days, and 56.9 g/m^2 between 46 and 90 days.

Loss of allochthonous detritus from the system is partially explained by downstream export. Post-flood values in the upper section and canyon of Aravaipa Creek, respectively, were reduced 70.0 and 68.5% by 16 to 45 days after spates, 85.6 and 87.2% by 46 to 90 days, and to 93.6 and 87.0% after more than 90 days. Corresponding values below the canyon were 38.1%, 76.2%, and 82.6%, respectively, with the slower rate of loss reflecting continuing accumulation of materials from upstream.

Drift of detrital material at a station near Turkey Creek ranged from 0.014 to 0.054 g/m^3 in five, 28-hour periods in 1975-76 (Schreiber 1978). Data for April, July, and October indicated drift rates of between 0.32 and 0.93%/day (average 0.54%/day) of standing crops in that reach. For January 1977, when standing crop of detritus was negligible (0.1 g/m^2; Table VI-4), the indicated drift rate was 15.1%, undoubtedly an artifact of sampling.

Table VI-4. Standing crops of finely-divided detritus in samples from Aravaipa Creek, Graham and Pinal counties, Arizona. Data are ash-free dry weights, g/m^2; numbers of samples are in parentheses.

Dates	Upper	Canyon	Lower
April 1975	3.2 (5)	7.5 (6)	23.7 (4)
June	4.3 (5)	6.5 (6)	7.5 (4)
September	53.8 (5)	94.7 (6)	42.0 (4)
October	15.1 (5)	22.6 (6)	28.0 (4)
December	Tr. (5)[1]	16.2 (6)	24.8 (4)
January-February 1976	0.1 (5)	6.5 (6)	7.5 (4)
March	4.3 (5)	6.5 (6)	9.7 (4)
April	5.4 (5)	6.7 (6)	9.6 (4)
September	39.8 (2)	44.1 (2)	31.2 (4)
October	20.5 (3)	24.8 (2)	33.4 (4)
November	4.3 (4)	---	9.7 (4)
January 1977	1.1 (4)	2.2 (2)	1.1 (4)
March	2.7 (4)	3.3 (1)	2.1 (4)
June	1.2 (2)	---	1.1 (2)
July[2]	0.5 (4)	---	1.3 (2)
July[2]	42.4 (2)	---	50.0 (2)
December	18.7 (2)	---	36.3 (2)
January 1978	12.8 (2)	---	30.0 (2)
March	9.4 (2)	---	14.9 (2)
April	---	---	17.6 (2)
Means, paired samples only	11.1 (53)	10.8 (55	22.2 (48
	11.3 (71)	---	21.5 (64)

---

[1] Tr. = less than 0.05 g/m^2

[2] Before and after dates in July when sustained flooding commenced.

Initial losses after flooding are higher than indicated by Schreiber's data (all of which was collected between discharges of 0.12 and 0.59 m^3/s, mean 0.33). Slopes in Fig. VI-3 imply transport (or some other factor causing declines) in standing crops in upper Aravaipa and its canyon of *ca*. 0.95 to 1.07 g/day in the first 30 or so days. Over the first 60 days, mean declines in the upper areas were 0.34 and 0.68 g/day, almost exactly that reported by Schreiber for instantaneous samples at discharges typical of that period of time after flooding. Slower indicated losses below the canyon, again reflecting transport into that area from above, are uniformly 0.39-0.40 g/day over the first 30 or 60 days (Fig. VI-3).

It is notable that sustained flooding between July and the end of sampling in April 1978, involving repeated rainfall that must have resulted in sheet flow over desert terrain, resulted in progressive declines in detritus. Onset of flooding in July resulted in a surge in standing crop from less than 0.8 g/m^2 to an average of 46.2 g/m^2 in the creek (Table VI-4). In December, after four major floods (Fig. VI-1), levels were at only 27.5 g/m^2, in January (following another spate), 21.4 g/m^2, in March (after large floods in February), 12.2 g/m^2, and a single downstream sample in April yielded 17.6 g/m^2. Watershed stores of transportable materials were apparently being depleted.

Gray (1980) found allochthonous detrital materials essentially gone from Sycamore Creek, Arizona, a few weeks after flood inputs, with a gradual buildup of autochthonous (algal) biomass replacing it. A similar pattern is evident in Aravaipa Creek (compare Figs. VI-2 and VI-3), yet no combinations of periphyton and detritus samples approach his maximum figures for standing crops. He recorded combined weights ranging from 178 to 2,000 g/m^2 (average 594.8 g/m^2, $n = 7$) after long periods (> 90 days) of low discharge. As noted

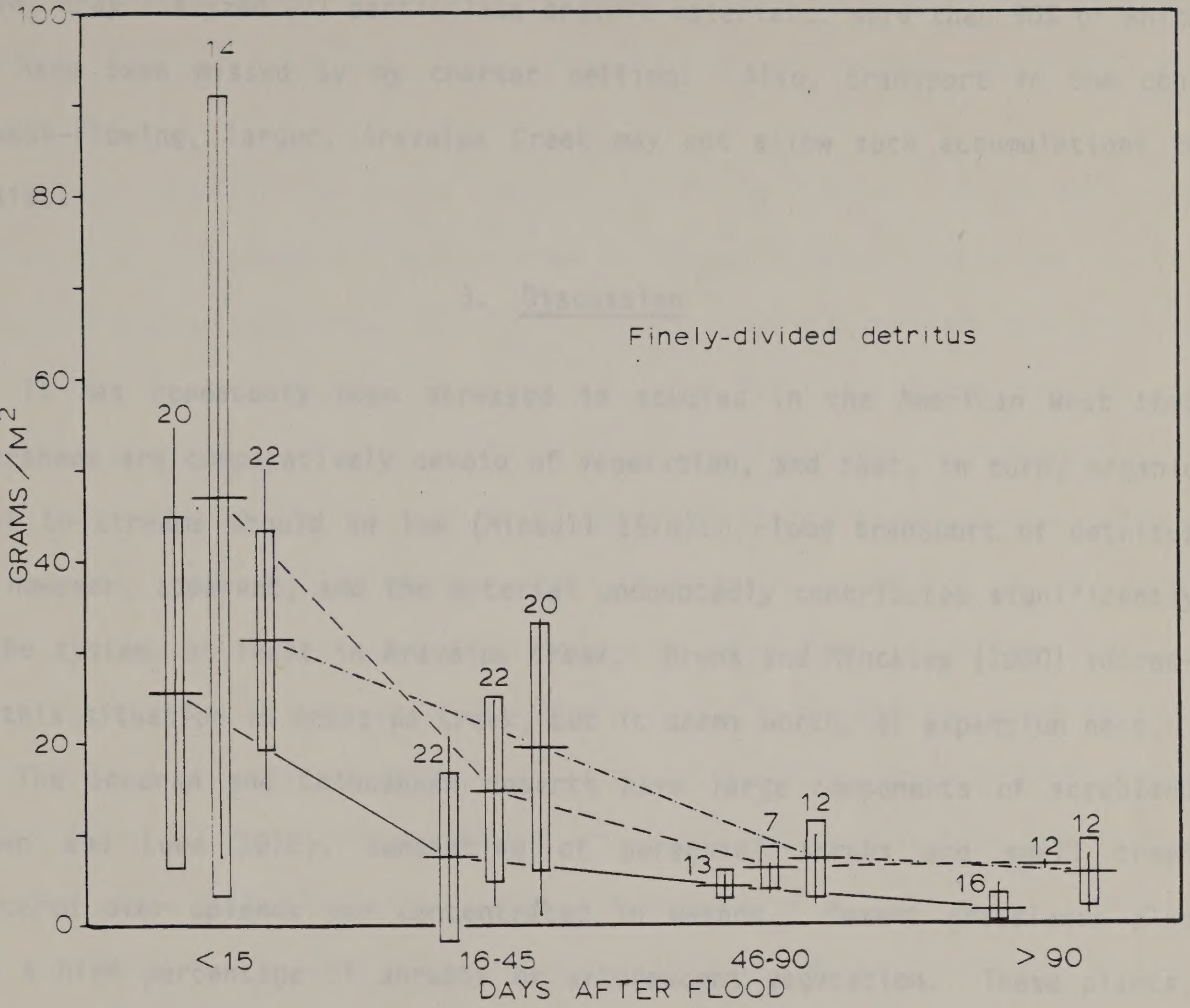

Figure VI-3. Standing crops of finely-divided detritus in and on bottom sediments of Aravaipa Creek, Graham and Pinal counties, Arizona, relative to days following a flooding event: symbols as in Figure VI-2.

above, Gray analyzed all particulate organic materials, more than 90% of which may have been missed by my coarser netting. Also, transport in the continuous-flowing, larger, Aravaipa Creek may not allow such accumulations to persist.

3. Discussion

It has repeatedly been stressed in studies in the American West that watersheds are comparatively devoid of vegetation, and that, in turn, organic input to streams should be low (Minsall 1978). Flood transport of detritus is, however, apparent, and the material undoubtedly contributes significantly to the system, at least in Aravaipa Creek. Bruns and Minckley (1980) addressed this situation in Aravaipa Creek, but it seems worthy of expansion here.

The Sonoran and Chihuahuan deserts have large components of scrubland (Brown and Lowe 1978), consisting of perennial shrubs and small trees scattered over uplands and concentrated in washes. Desert grasslands also have a high percentage of shrubby or arborescent vegetation. These plants, such as cresotebush, palo verde, bursage, and mesquite, are evergreen or winter deciduous, but if either, are drought deciduous and rainfall responsive. Protracted dry conditions result in leaf, stem, and even twig-fall as the plant dies back to its most resistant parts. Rapid responses to rainfall include full leaf production and often production of flowers and fruits, which also drop to the ground surface after maturation. Smaller plants, and shrubs and trees, are eaten by animals, and dry feces of desert-adapted forms accumulate along with larger feces of man's livestock (Forbes 1902). These materials dry further on ground surfaces that may achieve more than 65^{0} C (Hadley 1970), and may lie there with little disturbance other than

wind for long periods. Few desert arthropods or other groups feed on dried materials. Larger items may, however, be encased and reduced toward detritus by termites.

Abrupt rainfall in desert quickly mobilizes buoyant litter and concentrates it in ephemeral watercourses. Lines of debris stranded on the surface of coarse substrates when floods recede retain water, and are attacked by reducers as termites and other insects, and fungi. Repeated movement of material, and mixing it with sand, makes it more accessible to reduction in subsurface locales. By the time it is mobilized and transported by a definitive runoff event, debris may be the consistency of sawdust or a coarse powder, incorporated with inorganic bedload of an ephemeral, intermittent, or perennial stream. If the latter, instability of sandy bottoms promotes constant mixing, and organic materials are elutriated into surface flow (Bruns and Minckley 1980). Where sediments are deep, such elutriation may take a long time, but where bedrock is near, transport will be more rapid. Perhaps this explains in part the higher values of detrital material in samples from Aravaipa Canyon (Table VI-4), representing the interstitial standing crop transported there by flood plus rapid transport of materials from upstream.

Decline in abundance of allochtonous detritus must also be attributed in Aravaipa Creek to direct assimilation by animals. The percentage loss to this sink is unestimated, but must be substantial.

I propose that the relatively constant amount of detritus in sediments after _ca_. 60 days following flood represents a steady-state balance between transport and production of autochthonous detrital materials. If this is so, considerable amount of algae must be represented, and algal detritus may well

form a major basis for nutrition of animals in the system (see Koslucher and Minshall 1973).

C. Benthic Invertebrates

by W. L. Minckley and Stephen W. Burton

1. Introduction

Until recently, benthic invertebrates in desert streams of the American Southwest were essentially unknown. Bruns (1977) first dealt with the fauna of Aravaipa Creek, and this was expanded upon and published by Bruns and Minckley (1980). Minckley (1979b) summarized information for Arizona, including a number of unpublished reports, and Gray (1980) reported on communities of aquatic insects in the Sycamore Creek watershed, central Arizona. The present section reviews and further extends information from Bruns' original contribution, presents information on drift of benthic animals (Schreiber 1978), and discusses the invertebrate fauna of Aravaipa Creek in light of recent findings on life-history phenomena within that group (Gray 1980).

2. Methodology

Invertebrates were collected at intervals from April 1975 through April 1978 by Surber-type sampler (929 cm^2) with netting mesh of 228 um. If two samples were taken, one was from gravel and the other from cobble; single samples were from gravel bottoms. Materials were preserved in the field in 10% formalin solution; no corrections were made for possible shrinkage in preservative.

Organisms and organic debris were separated from inorganic materials by air elutriation (Lauff et al. 1961), with overflow particles retained by 203-um netting. Remaining substrate was visually inspected for heavy organisms, then discarded. If large numbers of animals were present, sub-samples were analyzed. Sub-samples were precise within limits considered acceptable by Elliott (1971). Identification of the fauna was with keys of Usinger (1956) and Edmondson (1959). Wet weights of organisms were determined after drying for one minute on blotting paper. Conversion to ash-free dry weight may be approximated by a factor of 0.1372 x wet weight, based upon 35 samples of mixed invertebrates fired for 4 hours at 550^{0} C.

Drift of aquatic invertebrates (and other materials as discussed before) was estimated by drift net of 333 um mesh. Nets were tethered between two sections of reinforcing rod driven into the stream bed in center of the channel. Care was taken to avoid contact with the bottom, and the lower frame of the net was kept three or more centimeters above the substrate to avoid agitation of materials by induced turbulence. Speed of flow at the sampling site was determined by the Embody (1927) cork-float method, or by current meter. A correction factor for volume of water filtered was computed from declining current-meter readings as meshes became clogged. Sampling was for 15 minutes at intervals through a 28-hour period. Materials collected were treated as for bottom samples. Drift was converted to numbers or mg/m^3 by use of the following formula:

$$D_1 \text{ or } D_2 = \frac{N \text{ or } W/T}{NF \times V} \times CF,$$

Table VI-5. Invertebrate taxa from aquatic habitats of the Aravaipa Creek drainage, Graham and Pinal counties, Arizona, 1975-78. Minimum numbers of species for each family are in parentheses. Symbols: X = primary occurrence; x = secondary; - generally absent or rare.

	Typical Habitats			
Taxa	Main-stream	Side Canyons	Tinajas	Rain Pools
INSECTA				
COLLEMBOLA (spring tails)				
Poduridae(1)				
Podura aquatica L.	-	X	-	-
Sminthuridae(1)				
Undetermined sp.	X	-	-	-
EPHEMEROPTERA (mayflies)				
Baetidae(4)				
Baetis sp. "A"	X	-	-	-
Baetis sp. "B"	X	x	-	-
Callibaetis sp.	x	X	x	-
Centroptilium sp.	X	-	-	-
Heptageniidae(2)				
Rhithrogena sp.	X	x	-	-
Heptagenia sp.	-	X	-	-
Ephemerellidae(1)				
Ephemerella micheneri Traver	X	x	-	-
Tricorythidae(3)				
Tricorythodes minutus Allen	X	x	-	-
T. dimorphus Allen	X	-	-	-
T. condylus Allen	X	-	-	-
Leptophebiidae(2)				
Choroterpes inornatus Eaton	X	x	-	-
Leptohypes apache Allen	X	-	-	-
ODONATA (dragon- and damselflies)				
Gomphidae(3)				
Aphylla(?) sp.	x	X	-	-
Undetermined sp.	x	X	-	-
Undetermined sp.	-	-	X	X
Aeshnidae(1) (darners)				
Aeshna sp.	-	-	X	-
Libellulidae(2)				
Dythemis(?) sp.	x	X	-	-
Undetermined sp.	-	x	X	-
Coenagrionidae(2)				
Isnura sp.	x	X	-	-
Coenagrion(?) sp.	x	X	-	-

Table VI-5. Continued.

Taxa	Typical Habitats			
	Main-stream	Side Canyons	Tinajas	Rain Pools
PLECOPTERA				
Capniidae(1)				
Capnia frisoni Baumann and Gaufin	X	x	-	-
HEMIPTERA (true bugs)				
Macroveliidae (1)				
Undetermined sp.	-	X	-	-
Veliidae (2) (broad-shouldered water striders)				
Rhagovelia sp.	-	X	-	-
Microvelia sp.	x	X	-	-
Gerridae(1) (water striders)				
Gerris sp.	-	X	X	x
Belostomatidae(2) (giant water bugs)				
Abedus herberti Hidalgo	x	X	x	-
Lethocerus medius (guerin)	-	-	X	-
Nepidae(1) (water scorpions)				
Ranatra sp.	-	X	-	-
Pleidae(1) (pigmy back swimmers)				
Plea sp.	-	X	-	-
Naucoridae(1) (creeping water bugs)				
Ambrysus sp.	X	x	-	-
Corixidae(2) (water boatmen)				
Graptocorixa sp.	X	X	-	-
Sigara sp.	-	X	-	-
Notonectidae(2) (back swimmers)				
Buenoa sp.	-	-	X	X
Notonecta sp.	-	x	X	X
Mesoveliidae(1) (water treaders)				
Mesovelia sp.	-	-	X	-
Gelastocoridae(1)				
Gelastocoris sp.	X	X	-	-
MEGALOPTERA				
Corydalidae(1) (hellgrammites)				
Corydalis sp.	X	-	-	-
TRICHOPTERA (caddis flies)				
Hydropsychidae(2)				
Cheumatopsyche sp.	X	x	-	-
Hydropsyche sp.	X	x	-	-
Rhyacophilidae (1)				
Rhyacophila sp.	-	X	-	-

Table VI-5. Continued.

Taxa	Typical Habitats Main-stream	 Side Canyons	 Tinajas	 Rain Pools
Glossosomatidae(1)				
Undetermined sp.	X	-	-	-
Hydroptilidae(3)				
Ochrotrichia sp.	X	x	-	-
Leucotrichia sp.	X	-	-	-
Mayatrichia sp.	X	-	-	-
Limnephilidae(1)				
Undetermined sp.	X	x	-	-
Heliocopsychidae(1)				
Helicopsyche sp.	X	-	-	-
LEPIDOPTERA (butterflies and moths)				
Pyralidae(1)				
Cataclysta sp.	X	-	-	-
COLEOPTERA (beetles)				
Gyrinidae(1) (whirligig beetles)				
Gyrinus sp.	-	X	X	-
Haliplidae(2) (crawling water beetles)				
Peltodytes sp.	x	X	x	-
Undetermined sp.	-	-	X	-
Dytiscidae(7) (predaceous diving beetles)				
Bidessus sp.	-	-	X	X
Deronectes sp.	X	X	X	x
Hydroporus sp.	X	X	-	-
Laccophilus sp.	X	X	x	x
Thermonectes sp.	-	-	X	x
Undetermined spp.	-	x	X	-
Hydrophilidae(7) (water scavenger beetles)				
Berosus spp.	-	X	X	-
Laccobius sp.	-	-	X	-
Tropisternus sp.	X	x	x	-
Undetermined spp.	-	-	X	X
Psephenidae(1) (water pennies)				
Psephenus sp.	X	-	-	-
Dryopidae(1)				
Helichus sp.	X	X	-	-
Helodidae(1)				
Undetermined sp.	-	X	-	-
Elmidae(2) (riffle beetles)				
Undetermined spp.	X	X	-	-

Table VI-5. Continued.

Taxa	Typical Habitats Main-stream	 Side Canyons	 Tinajas	 Rain Pools
DIPTERA				
Blephariceridae(1) (net-winged midges)				
Blepharicera(?) sp.	X	-	-	-
Tipulidae(2) (crane flies)				
Undetermined sp.	X	X	-	-
Undetermined sp.	-	X	X	-
Culicidae(3)				
Aedes sp.	-	-	X	X
Culex sp.	-	-	X	X
Anopheles sp.	X	X	-	-
Psychodidae(1) (moth flies)				
Pericoma(?) sp.	X	X	-	-
Ceratopogonidae(4) (biting midges)				
Forcipomyia(?) sp.	-	X	x	-
Probezzia sp.	X	X	-	-
Undetermined spp.	X	x	-	-
Simuliidae(2) (black flies)				
Simulium sp.	X	x	-	-
Undetermined sp.	X	-	-	-
Chironomidae(13) (chironomid midges)				
Tanypodini spp.	X	X	X	x
Pentaneurini spp.	X	X	X	x
Orthocladiinae spp.	X	X	-	-
Chironominae spp.	X	X	X	x
Tanytarsini spp.	X	-	-	-
Dixidae(1) (dixid midges)				
Dixa sp.	X	x	-	-
Stratiomyidae(2) (soldier flies)				
Undetermined spp.	X	x	-	-
Tabanidae(3) (horse flies)				
Silvius(?) sp.	X	-	-	-
Tabanus spp.	X	X	x	-
Dolichopodidae(1)				
Undetermined sp.	X	-	-	-
Empididae(1) (dance flies)				
Undetermined sp.	X	x	-	-
Ephydridae(1) (shore and brine flies)				
Undetermined sp.	X	x	-	-
Scatophagidae(1) (=Anthomyidae in part; dung flies)				
Undetermined sp.	X	x	x	-

Table VI-5. Continued.

Taxa	Typical Habitats			
	Main-stream	Side Canyons	Tinajas	Rain Pools
Muscidae(2) (=Anthomyiidae, in part; house flies)				
Undetermined sp.	X	x	-	-
Undetermined sp.	-	-	X	-
CRUSTACEA				
Copepoda				
Undetermined families(2)				
Undetermined spp.	-	-	X	X
Cladocera				
Undetermined families(3)				
Undetermined spp.	-	X	X	-
Ostracoda				
Cypridae(1)				
Cypris sp.	x	X	-	-
Undetermined families(2)				
Undetermined spp.	-	-	X	X
Conchostraca				
Undetermined families(2)				
Undetermined spp.	-	-	-	X
Anacostraca				
Streptocephalidae(2) (fairy shrimps)				
Streptocephalus sp.	-	-	-	X
Thamnocephalus sp.	-	-	-	X
Apidae(1) (tadpole shrimps)				
Apus longicaudatus L.	-	-	-	X
ACARINA				
Hydracarina				
Undetermined family(1)				
Undetermined sp.	X	X	-	-
ANNELIDA				
Oligochaeta				
Undetermined families(3)				
Undetermined spp.	X	X	X	-
Hirudinea				
Undetermined families(1)				
Undetermined sp.	X	x	-	-
NEMATODA				
Undetermined families(1)				
Undetermined sp.	X	x	x	-
TURBELLARIA				
Planariidae(1)				
Undetermined sp.	X	X	-	-

Table VI-5. Continued.

Taxa	Typical Habitats Main-stream	 Side Canyons	 Tinajas	 Rain Pools
GORDIODEA				
Undetermined family(1)				
Undetermined sp.	X	x	-	-
HYDROZOA				
Hydridae(1)				
Hydra(?) sp.	X	-	-	-
MOLLUSCA				
Gastropoda				
Physidae(1)				
Physa sp.	x	X	X	-
Spaeriidae(1)				
Pisidium sp.	-	X	-	-

where D_1 is number or D_2 is mg/m^3, N is number of organisms or W is mg/unit time (T), NF is net face area (m^2), V is water velocity (m/s), and CF is the conversion factor derived from current meter readings.

3. Results

The invertebrate fauna of the Aravaipa Creek system is rich and diversified, both in numbers of taxa (Table VI-5) and in numbers of individuals. Bruns and Minckley (1980) recorded 63 taxa of invertebrates, of which 56 were insects, and a total of 133 (109 insects) now are known from the drainage. Gray (1980) similarly recorded 99 taxa of aquatic insects from the Sycamore Creek watershed, central Arizona. For further comparison, Bane and Lind (1978) obtained 115 total invertebrates, most of which were insects, from Tornillo Creek, Texas, in the Chihuahuan Desert. Piceance Creek, Colorado (Great Basin Desert), supported 83 invertebrate taxa, of which 69 were insects (Gray and Ward 1979). Other studies in the Southwest (Minckley 1979b) generally included identifications only to family (or higher category, Table VI-6).

a. Benthic organisms. Additional sampling in Aravaipa Creek confirms patterns described by Bruns (1977) and Bruns and Minckley (1980) that invertebrates are most abundant near the headwaters, and that lowest numbers and biomass are within the canyon segment of the stream (Fig. VI-4). Numbers of animals generally ranged between 1.0 and 2.0 x 10^5/m^2 and between 10 and 20 g/m^2 wet weight (Figs. VI-5 - VI-6). Average number of taxa per sample rarely exceeded 20 (Fig. VI-7). A station at the origin of the system was exceptional, with numbers of organisms ranging to more than 2.5 x 10^5 individuals at a maximum. This was attributable to relatively high standing crops of

Table VI-6. Comparative information on benthic invertebrates in streams of Arizona and New Mexico.

Location	Taxa/ Sample	Total Families	Individuals /m^2	Type of Data	Reference
Gila River, eastern AZ	8.4	34	4,186	Autumn 1976-Winter 1978	Minckley 1979b
San Francisco River, eastern AZ	7.6	26	3,880	"	"
Bonita Creek, eastern AZ	9.5	46	5,648	"	"
Eagle Creek, eastern AZ	9.3	23	1,052	Spring-Winter 1977	"
San Francisco River, western NM	11.8	31	145	May-June 1977	Anderson & Turner 1978
Upper Eagle Creek, eastern AZ	---	15-21	666-1,279	June 1976	Kynard 1976
Blue River drainage, eastern AZ (8 creeks)	---	18-28	-----	Summer 1976-1977	Silvey and Thompson 1978
Sycamore Creek, central AZ	---	49	8×10^4	At stability	Gray 1980
Aravaipa Creek, eastern AZ	---	50	12,240	Annual Ave.	Bruns 1977, Bruns and Minckley 1980
	10.0	64	_ca._ 6,000 2×10^4	Over-all At stability	Present study

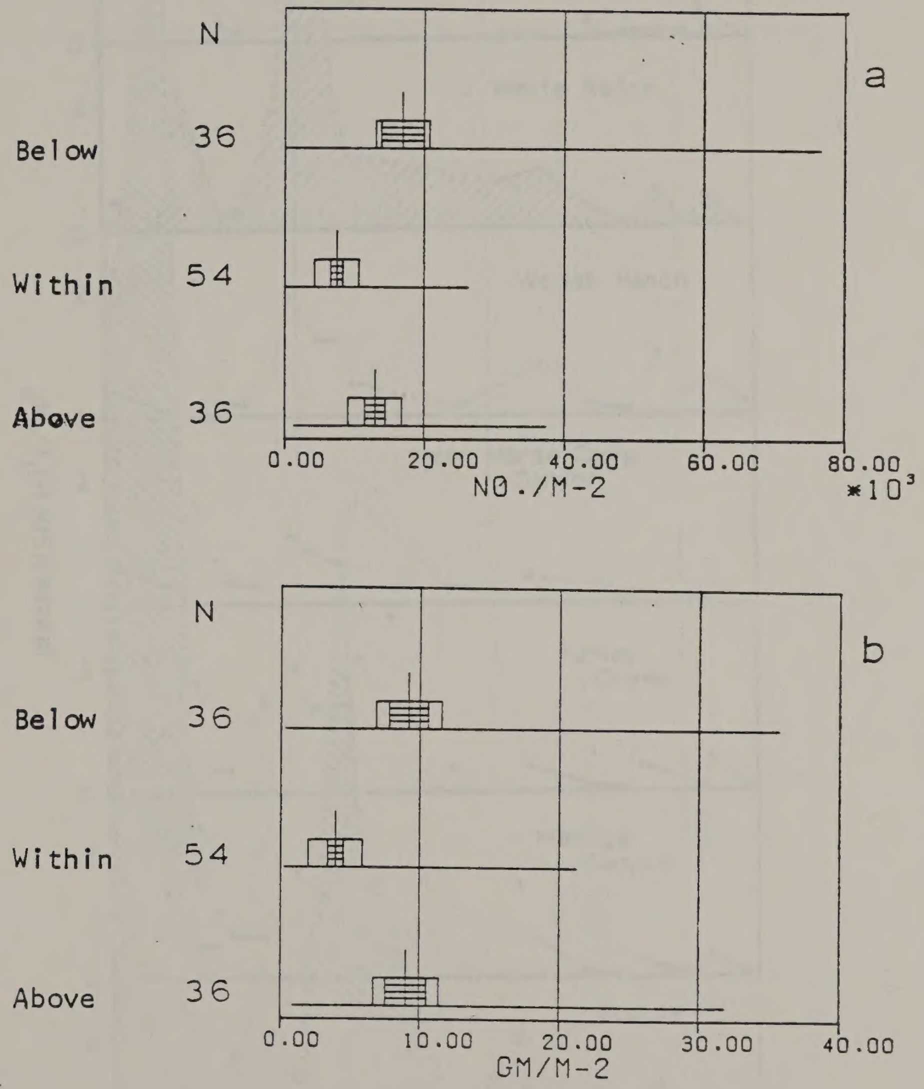

Figure VI-4. Summary of mean numbers and biomass of benthic invertebrates in Aravaipa Creek, Graham and Pinal counties, Arizona, 1975-76, above, within, and below the canyon segment (from Bruns and Minckley 1980).

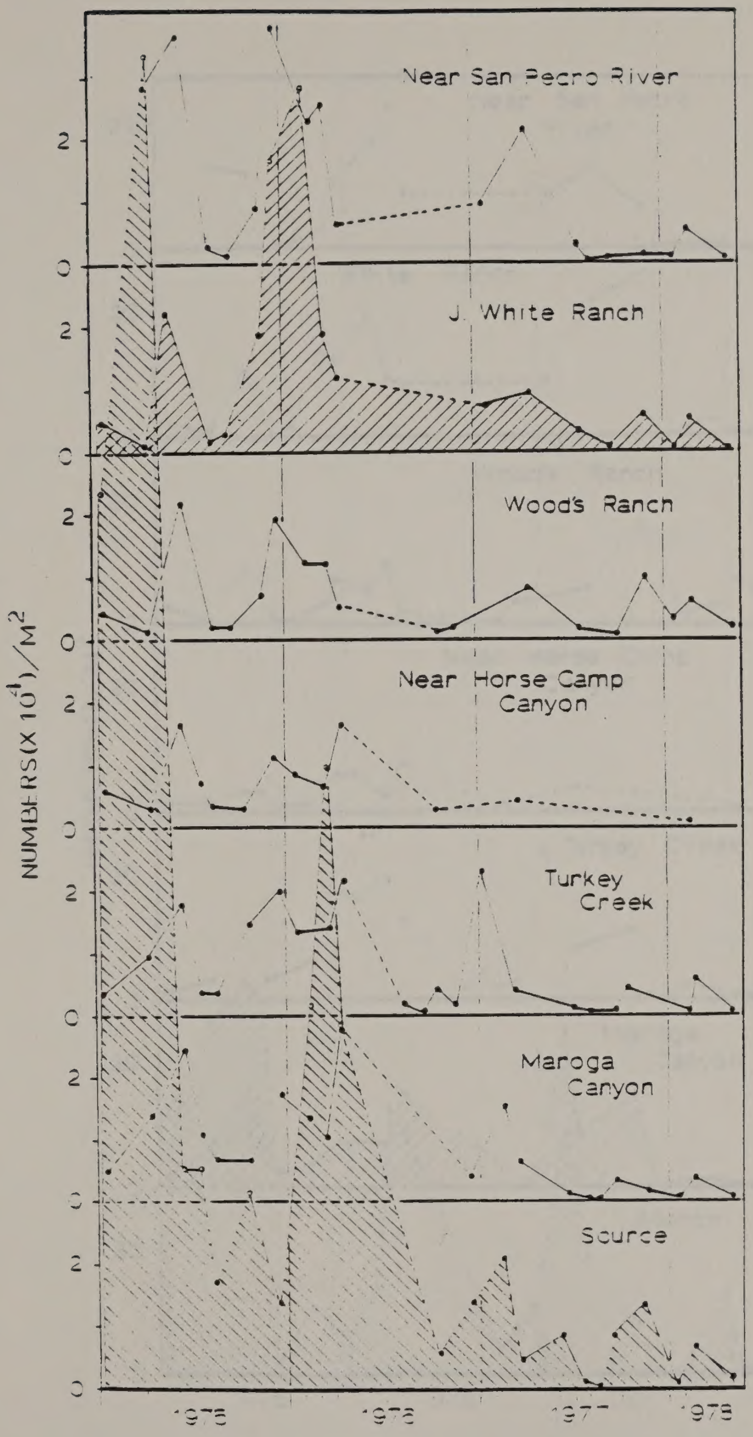

Figure VI-5. Numbers ($/m^2$) of invertebrates in samples from various stations in Aravaipa Creek, Graham and Pinal counties, Arizona, 1975-1978; see text for further explanation.

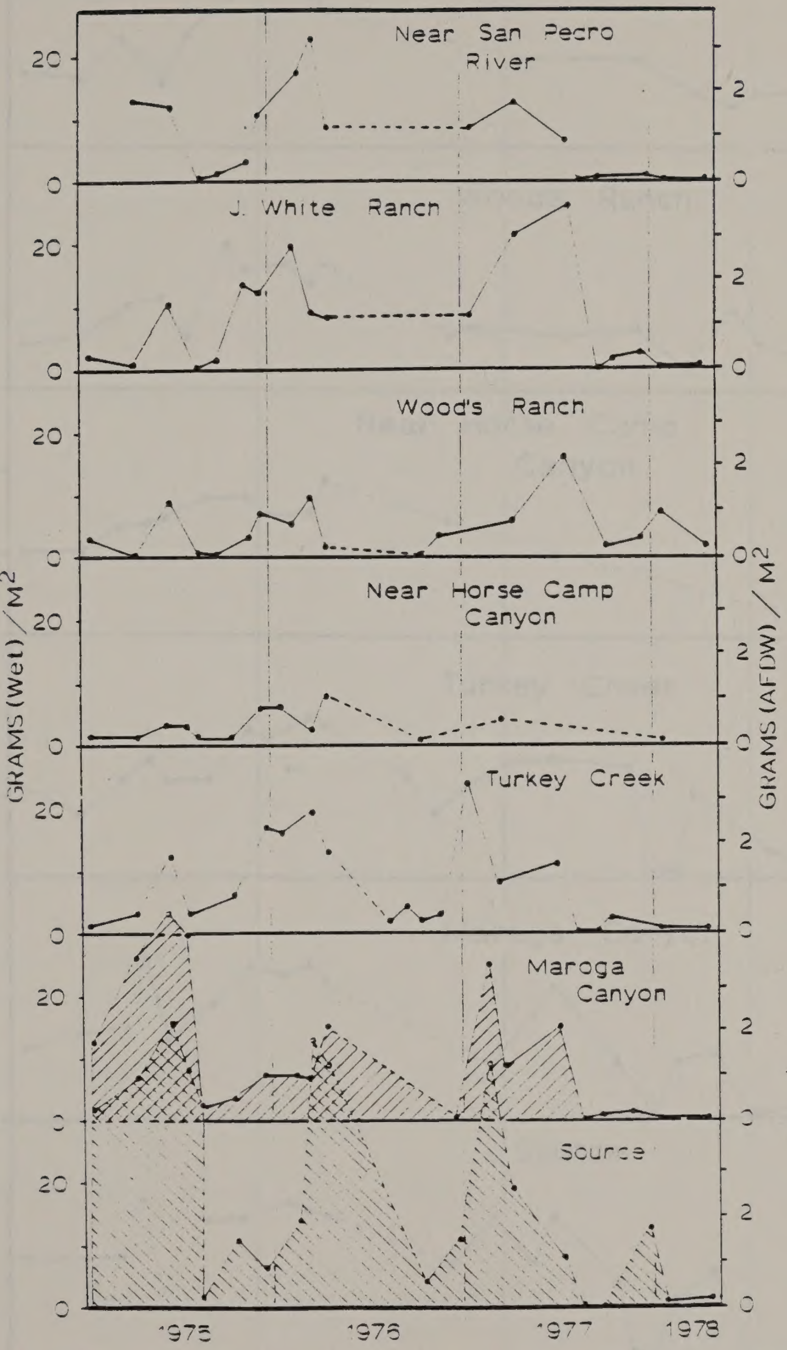

Figure VI-6. Weights (g/m^2, blotted wet weight) of invertebrates in samples from Aravaipa Creek, Graham and Pinal counties, Arizona, 1975-1978; see text for further explanation.

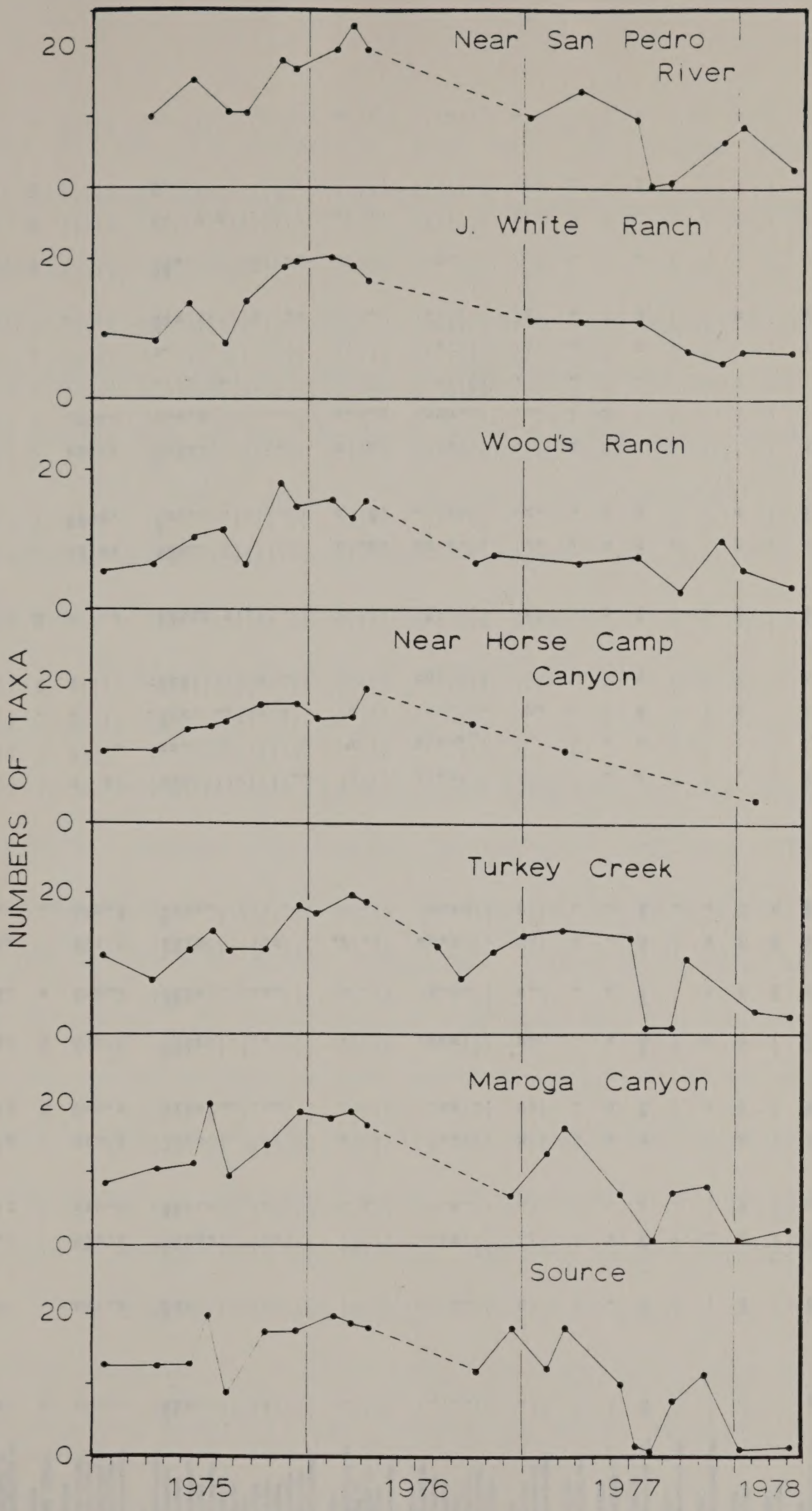

Figure VI-7. Number of taxa ($/m^2$) of invertebrates in samples from Aravaipa Creek, Graham and Pinal counties, Arizona 1975-1978; see text for further explanation.

Table VI-7. Average densities of important benthic invertebrates in Aravaipa Creek, Graham and Pinal counties, Arizona.

Taxa (samples)	Jan (2)	Feb	Mar	Apr (14)	May	Jun (14)	Jul (14)	Aug	Sep (14)	Oct (14)	Nov	Dec (14)	Jan (14)	Feb	Mar (14)	Apr (14)	May	Jun	Jul	Aug (6)	Sep (3)	Oct (9)	Nov (3)	Dec	1977 Jan (7)	Feb	Mar (10)	Apr (6)	May	Jun (7)	Jul (13)	Aug (4)	Sep (4)	Oct (6)	Nov	Dec (7)	1978 Jan (4)	Feb (6)	Mar	Apr (7)
EPHEMEROPTERA																																								
Baetis spp.	565			1306		3639	1056		763	3176		4988	5776		3292	5184				474	115	1101	305		3358		1231	1920		1141	30	----	3	331		2295	38	14		39
Choroterpes sp.	172			164		2571	870		644	861		1382	733		1197	987				22	25	24	22		104		372	124		216	80	----	----	----		22	27	----		11
Ephemerella sp.	----			495		14	----		----	----		----	570		507	1014				----	11	22	----		14		----	3		14	----	----	----	----		----	----	----		----
Tricorythodes spp.	215			379		4928	309		224	286		615	741		625	1359				90	----	----	----		594		2143	3021		1644	91	----	----	75		----	229	7		1
Rhithrogena sp.	22			23		6	----		----	----		46	145		55	5				----	----	----	----		----		----	----		----	----	----	----	----		----	----	----		----
Centroptilium sp.	----			----		----	43		38	54		----	6		9	6				----	----	----	----		----		----	----		----	----	----	----	----		----	----	----		----
PLECOPTERA																																								
Capnia frisoni	32			6		----	----		----	203		1610	86		----	9				----	----	7	255		325		2	----		----	----	----	----	----		393	527	129		30
TRICHOPTERA																																								
Hydropsychidae	11			18		110	116		24	234		394	313		325	448				14	161	108	29		36		15	832		64	3	----	----	2		----	----	----		----
Hydroptilidae	11			56		411	50		10	20		77	40		222	192				----	----	----	----		----		214	219		17	63	----	----	----		----	----	----		----
Helicopsyche sp.	5			----		26	53		3	17		35	58		49	27				----	----	----	----		----		----	57		31	397	----	----	----		----	----	----		----
Limnephilidae	2			3		1	2		----	2		----	9		----	9				18	----	----	----		4		28	54		2	14	----	----	----		----	----	----		----
Glossosomatidae	4			12		15	130		21	71		143	315		91	268				----	2	----	----		28		44	2		14	1	----	----	----		----	----	----		----
DIPTERA																																								
Blephariceridae	----			----		----	----		----	----		----	----		----	----				----	----	2	11		2		----	----		----	----	----	----	----		----	----	----		----
Chironomidae	2594			1628		6165	690		435	1738		6616	5186		4410	2506				99	11	1609	1563		1848		749	2655		1643	37	4	11	2056		1835	175	158		18
Simuliidae	118			100		130	472		1171	714		2481	1683		268	178				2174	47	126	492		429		1170	38		13	2	----	4	794		1091	46	4		----
Ceratopogonidae	22			55		108	49		14	143		487	714		334	73				47	4	90	104		161		29	5		109	36	----	----	30		4	----	----		----
Tabanidae	1			----		33	1		17	22		28	45		29	8				----	----	1	----		18		1	7		14	7	----	----	----		----	----	----		----
Stratiomyidae	----			----		6	15		----	----		3	----		----	3				----	----	----	----		27		----	7		1	22	---	----	----		----	23	----		----
Muscidae	----			----		----	----		----	5		----	7		----	----				----	----	5	----		----		----	----		----	----	----	----	----		----	----	----		----
Culicidae	----			----		----	----		3	3		1	----		----	----				----	----	2	----		22		126	2		----	----	4	----	----		----	19	----		----
Dixidae	----			2		----	1		----	----		----	3		----	----				4	----	----	----		----		----	----		----	----	----	----	----		----	----	----		----
Tipulidae	----			----		----	----		----	1		----	3		----	----				----	----	----	----		----		----	11		----	----	----	----	----		----	----	----		----
Ephydridae	64			17		12	6		----	5		6	12		12	----				----	----	11	47		----		----	----		----	----	----	----	19		117	----	----		----
Empididae	----			----		13	----		----	3		----	3		12	----				----	----	1	----		----		----	----		----	1	----	----	----		----	----	----		----
Psychodidae	----			----		----	----		----	----		----	----		----	3				----	----	30	7		3		----	9		1	1	----	----	----		----	----	----		----
Anthomyidae	----			----		----	----		----	----		----	----		----	----				7	----	----	----		----		----	----		----	----	----	----	4		3	----	----		----
Dolichopodidae	----			----		----	----		----	----		----	----		----	----				4	7	7	----		----		----	----		----	----	----	----	32		38	----	4		----
HEMIPTERA																																								
Graptocorixa sp.	4			----		----	3		6	3		6	6		25	12				----	----	----	----		----		13	14		24	3	----	----	----		----	4	----		3
Abedus sp.	----			----		----	----		----	----		----	----		----	----				4	14	5	----		----		----	----		----	2	----	----	----		----	----	----		
Ambrysus sp.	----			----		----	6		----	3		----	3		3	4				----	----	----	----		----		2	----		----	17	----	----	----		----	----	----		----
Veliidae	----			----		----	----		----	----		----	----		----	----				----	----	----	----		----		38	165		17	3	----	----	9		----	----	----		4
Notonectidae	----			----		----	----		----	----		----	----		----	----				----	----	----	----		----		2	----		----	17	----	----	----		----	----	----		----
COLEOPTERA																																								
Hydrophilidae	----			----		1	----		----	----		----	----		8	3				7	29	----	11		7		32	2		----	----	----	----	----		----	----	----		----
Dytiscidae	5			3		6	----		----	1		28	19		16	12				----	----	----	29		160		12	----		----	17	----	----	2		----	----	----		----
Dryopidae	----			----		12	3		6	13		18	7		8	3				4	4	1	----		----		----	----		----	15	11	4	----		27	----	----		----
Elmidae	7			13		20	46		3	39		50	30		52	46				14	7	2	----		2		6	36		17	92	----	----	----		9	----	----		2
Haliplidae	2			3		----	3		----	----		----	6		----	12				----	----	----	----		----		1	43		----	3	----	----	----		----	----	----		----
Psephenidae	----			----		----	----		----	5		----	----		----	----				----	----	----	----		----		----	----		----	1	----	----	----		----	----	----		----
Helodidae	----			----		----	----		----	----		----	----		----	----				----	----	2	----		----		----	----		----	----	----	----	----		----	----	----		----
ODONATA																																								
Gomphidae	2			10		3	4		33	84		52	48		51	24				----	----	----	----		----		----	4		2	----	----	----	----		----	----	----		2
Libellulidae	----			----		----	----		----	15		6	7		6	----				----	4	17	----		29		2	14		----	3	----	----	34		----	----	----		----
Coenagrionidae	----			----		----	----		----	----		----	----		----	----				----	----	2	----		----		9	4		----	5	----	----	----		----	----	----		----
MEGALOPTERA																																								
Corydalis sp.	----			----		----	3		15	7		1	6		10	2				----	----	1	4		4		6	5		12	3	1	2	2		5	----	1		----
LEPIDOPTERA																																								
Cataclysta sp.	----			6		21	6		6	13		15	18		5	6				3	9	----	----		14		11	13		32	43	----	----	----		----	----	----		----
OLIGOCHAETA																																								
Undetermined spp.	205			1241		629	24		40	621		2000	1482		923	255				11	2	171	14		244		194	14		8	----	4	15	67		8	7	11		3
HIRUDINEA																																								
Undetermined spp.	----			----		----	1		----	----		----	----		----	3				----	----	----	----		----		2	----		1	----	----	----	----		----	----	----		----
NEMATODA																																								
Undetermined spp.	----			----		3	----		----	12		69	47		30	6				----	----	----	----		----		----	----		----	----	----	----	----		----	----	----		----
OSTRACODA																																								
Cypridae	----			118		38	169		28	143		137	197		205	311				4	----	110	----		1270		41	74		----	----	----	----	22		----	----	----		7
HYDRAZOA																																								
Hydridae	----			----		----	----		----	----		----	378		338	95				----	----	----	----		----		4	----		----	----	----	----	----		----	----	----		----
ACARINA																																								
Undetermined spp.	43			129		121	76		32	131		437	731		755	509				24	----	23	25		495		73	176		83	----	----	30	28		5	----	----		----
TURBELLARIA																																								
Planariidae	----			6		154	48		----	----		----	3		8	33				----	----	62	----		----		67	95		25	----	----	----	----		----	----	----		----
GASTROPODA																																								
Physa sp.	----			----		----	----		----	----		----	----		----	----				----	----	----	----		2		1	13		5	----	----	----	----		----	----	----		----

filamentous algae and detrital materials, both of which enhance invertebrate populations, and a coarse sand substrate that supported a large interstitial (hyporheic) fauna (Bruns and Minckley 1980).

Benthic invertebrates varied widely in abundance in Aravaipa Creek, but a general pattern existed of greater numbers of individuals and taxa and greater biomass in later winter and spring, followed by a decline during summer rains and flooding. In 1977, small spates in January and February (Fig. VI-1) apparently suppressed populations, and onset of severe and sustained flooding in July progressively forced the fauna lower. Benthic invertebrates were markedly reduced in numbers and biomass in winter 1977-78 compared to earlier periods, and remained so the following spring (Figs. VI-5 - VI-7; Table VI-7).

Responses of the invertebrate fauna to flooding are further examined in Figures VI-8 and VI-9. Numbers immediately following a spate were often fewer than $50/m^2$, yet means for the period 0 to 15 days following a flooding event averaged near 4,000 within the canyon and below. Some floods recorded at the downstream gage originated in side canyons, so data for the upper stations include some samples in which numbers were not influenced at all by high water (some are excluded in Fig. VI-8; see legend), and about 8,000 individuals were present per square meter in the upper area. Biomass after flooding was reduced to less than 2.0 g/m^2 in all stream sections (again excluding some upstream samples), and numbers of taxa were similarly affected. In the period 16 to 45 days after flooding, most parameters increased, with some lag within the canyon, and relative stability was achieved by 46 to 90 days after disruption.

b. Drifting invertebrates. Downstream drift of aquatic insects was recognized by Denham (1938) as a basic pattern of their ecology, a way for

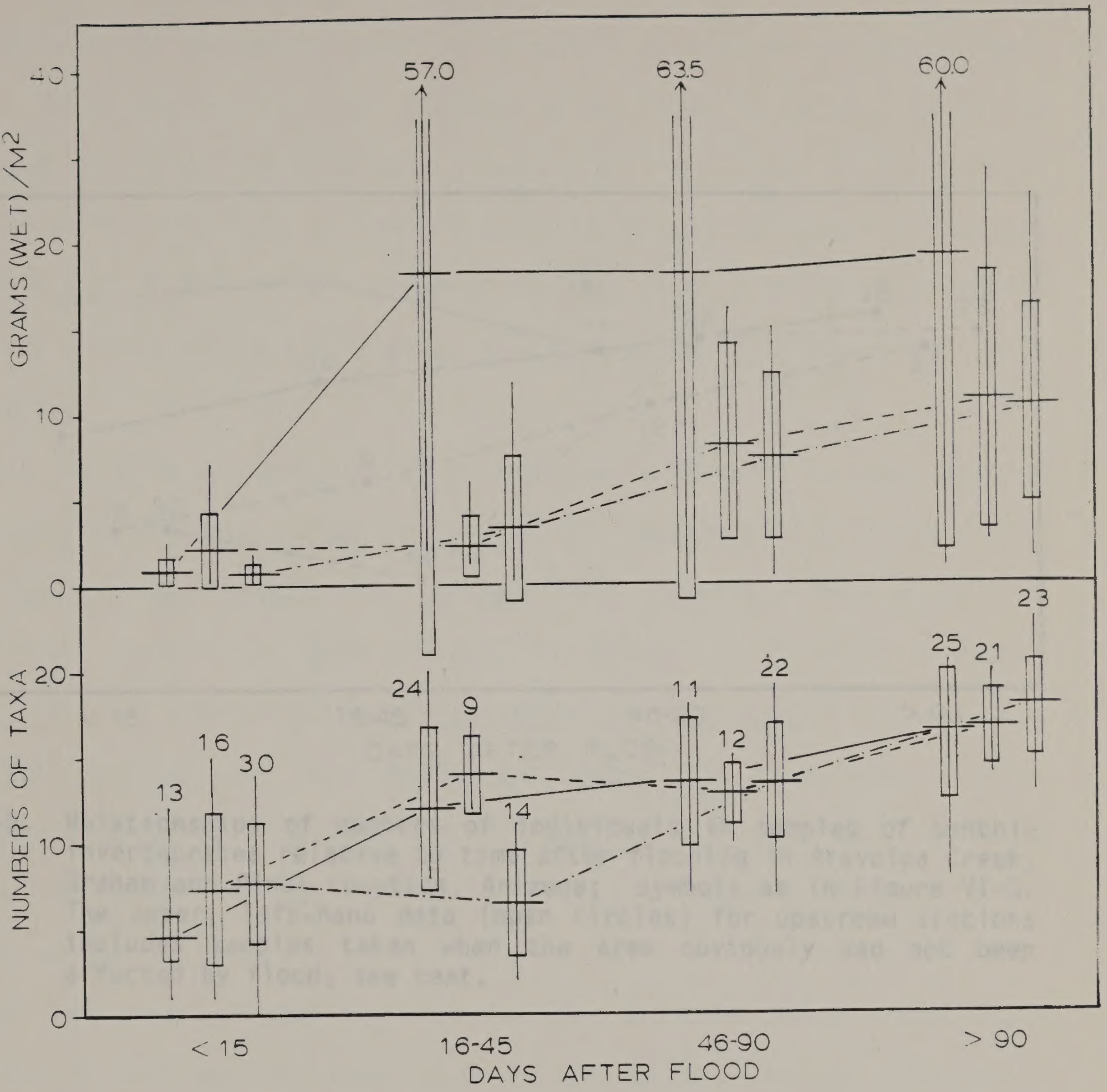

Figure VI-8. Relationships of biomass and numbers of taxa in samples of benthic invertebrates relative to time after flooding in Aravaipa Creek, Graham and Pinal counties, Arizona: symbols as in Figure VI-2.

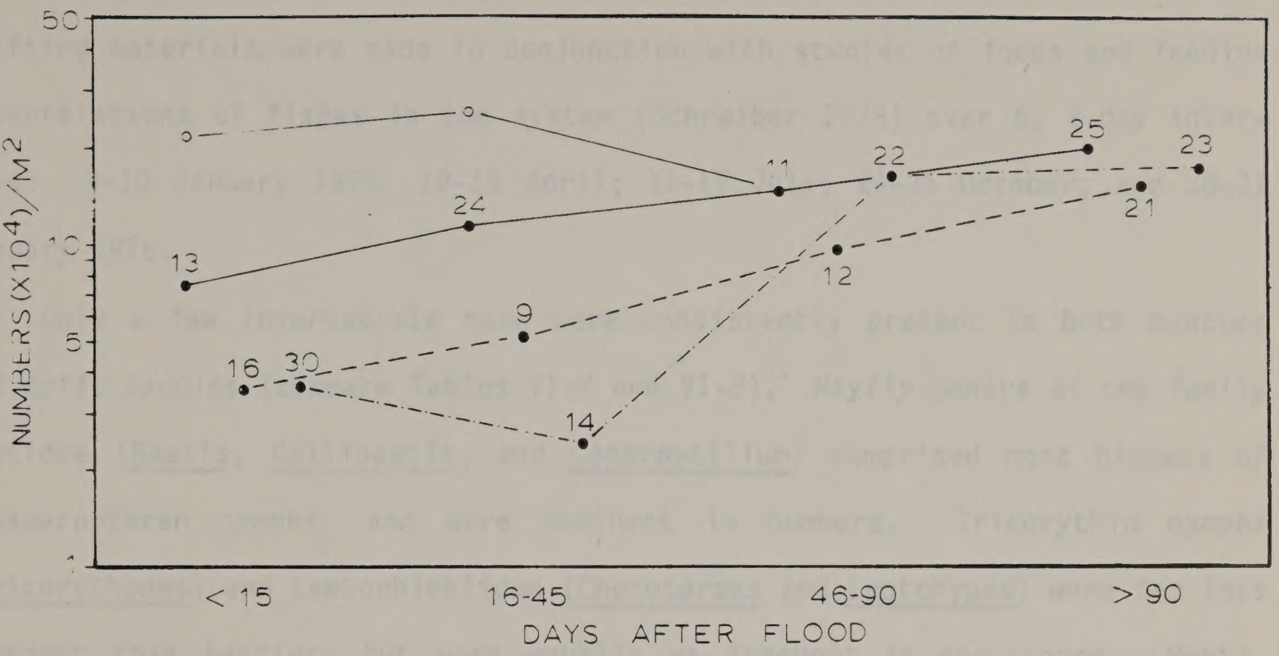

Figure VI-9. Relationships of numbers of individuals in samples of benthic invertebrates relative to time after flooding in Aravaipa Creek, Graham and Pinal counties, Arizona; symbols as in Figure VI-3. The upper, left-hand data (open circles) for upstream stations includes samples taken when the area obviously had not been affected by flood; see text.

species to colonize an entire reach of stream from upstream points of oviposition. Since that time, quantification of drift as an adjunct to bottom sampling has increased in importance (Waters 1972). Field collections of drifting materials were made in conjunction with studies of foods and feeding interrelations of fishes in the system (Schreiber 1978) over 5, 2-day intervals: 9-10 January 1975; 18-19 April; 11-12 July; 24-25 October; and 30-31 January 1976.

Only a few invertebrate taxa were consistently present in both benthos and drift samples (compare Tables VI-7 and VI-8). Mayfly genera of the family Baetidae (Baetis, Callibaetis, and Centroptilium) comprised most biomass of ephemeropteran nymphs, and were dominant in numbers. Tricorythid nymphs (Tricorythodes) and Leptophlebiidae (Choroterpes and Leptohypes) were far less abundant than baetids, but were equally as frequent in occurrence. Heptageniid (Rithrogena) and ephemerellid (Ephemerella) nymphs were abundant seasonally (winter-spring) in benthos samples, and were present in drift during the same periods.

Larvae and pupae of the dipteran families Chironomidae and Simuliidae were present in all periods, both in drift and benthic samples, were relatively important in terms of biomass, and were often present in large numbers (Tables VI-8). Chironomid adults were in all drift samples, forming significant proportions of total biomass. Simuliid adults were uncommon, but were taken in drift in 4 of 5 sampling periods.

Water mites (Acarina) were in all benthic and drift samples, but numbers and weights comprised a miniscule percentage of totals. Microcrustaceans, especially cyprid ostracods, also were consistent in occurrence, but of minor consequence in weight.

Table VI-8. Numbers and biomass (mg/m^3, wet weight) of invertebrates and other items in drift samples from Aravaipa Creek, Arizona, 1975-76. Items which did not occur as at least 1.0% in averages of at least one sampling period are lumped as "other."

Items	Sampling Periods January No.	 January Wt.	 April No.	 April Wt.	 July No.	 July Wt.	 October No.	 October Wt.	 January No.	 January Wt.
EPHEMEROPTERA										
Undetermined adults	0.5	2.3	0.3	1.4	0.2	1.1	0.1	0.7	0.5	2.4
Baetidae nymphs	8.4	14.6	15.7	7.8	6.7	2.3	14.9	9.3	19.2	20.6
Tricorythidae nymphs	4.7	6.0	7.0	4.9	1.6	0.7	7.2	0.7	2.6	2.0
Heptageniidae nymphs	Tr.[1]	0.2	---	---	---	---	---	---	0.2	1.1
Leptophlebiidae nymphs	0.2	0.2	0.2	0.4	0.7	1.7	0.3	0.1	0.3	0.6
Ephemerellidae nymphs	---	---	0.4	0.6	---	---	---	---	---	---
PLECOPTERA										
Capniidae nymphs	2.0	7.5	Tr.	Tr.	---	---	0.1	Tr.	0.1	0.5
ODONATA										
Gomphidae nymphs	0.2	0.5	---	---	0.1	0.3	0.3	1.3	---	---
HEMIPTERA										
Corixidae adults	0.2	3.6	0.4	9.9	0.1	0.7	0.3	3.3	0.2	5.0
TRICHOPTERA										
Hydropsychidae larvae	---	---	0.3	1.4	0.1	0.2	0.1	0.5	0.5	3.3
Glossosomatidae larvae	---	---	---	---	0.7	0.2	0.2	0.4	0.2	Tr.
DIPTERA										
Chironomid adults	3.4	2.2	1.1	0.7	0.6	0.4	1.2	0.8	3.5	2.3
Chironomid larvae and pupae	14.4	7.7	7.1	4.0	2.3	1.4	3.3	1.9	4.3	2.4

Table VI-8. Continued.

Items	January No.	 Wt.	April No.	 Wt.	Sampling Periods July No.	 Wt.	October No.	 Wt.	January No.	 Wt.
DIPTERA (con't.)										
Simuliidae adults	0.1	0.1	Tr.	Tr.	---	---	0.3	1.3	0.1	0.1
Simuliidae larvae	6.1	4.6	2.6	2.2	1.5	1.4	3.9	2.4	2.7	2.0
Ceratopogonidae larvae	0.6	0.5	0.1	Tr.	0.6	0.3	0.1	0.1	---	---
Ephydridae larvae	0.9	0.6	---	---	---	---	---	---	0.1	Tr.
Stratiomyiidae larvae	---	---	---	---	0.3	1.1	---	---	Tr.	Tr.
LEPIDOPTERA										
Pyralidae larvae	---	---	0.1	0.2	---	---	0.1	0.4	---	---
COLEOPTERA										
Undetermined terrestrial adults	0.1	0.1	0.1	0.1	0.1	0.9	0.3	0.4	---	---
ACARINA										
Undetermined taxa	1.1	0.1	2.5	1.0	1.5	0.2	1.1	0.1	3.7	0.3
CRUSTACEA										
Ostracoda (Cypridae)	5.7	0.2	4.3	0.4	7.8	0.8	4.6	0.2	14.9	0.5
Cladocera (Chydoridae)	---	---	39.7	0.6	Tr.	Tr.	---	---	Tr.	Tr.
Copepoda (Cyclopoidea)	2.0	0.1	2.0	0.1	1.9	Tr.	1.1	Tr.	0.5	Tr.
ANNELIDA										
Undetermined Oligochaeta taxa	1.7	4.6	3.6	6.1	0.5	0.9	0.3	0.5	0.1	0.2

Table VI-8. Concluded.

Items	Sampling Periods January No.	 Wt.	 April No.	 Wt.	 July No.	 Wt.	 October No.	 Wt.	 January No.	 Wt.
OTHER ANIMAL ITEMS										
Aquatic nymphs and larvae[2]	0.5	0.3	0.2	0.1	---	---	0.2	0.1	---	---
Emerged aquatic insects[3]	0.1	0.2	---	---	0.2	0.1	---	---	Tr.	0.1
Terrestrial insects[4]	0.2	0.1	0.2	0.1	0.3	0.1	0.2	0.1	0.1	Tr.
PLANT MATERIALS										
Diatoms	Na.[5]	Tr.	Na.	Tr.	Na.	Tr.	Na.	Tr.	Na.	Tr.
Filamentous algae	Na.	Tr.	Na.	Tr.	Na.	Tr.	Na.	Tr.	Na.	301.4
Detritus[6]	Na.	596.0	Na.	271.3	Na.	609.1	Na.	1,068.0	Na.	494.5
TOTALS										
Excluding plant materials	53.1	56.3	86.8	40.5	27.8	14.8	39.9	28.2	53.8	43.4
Including plant materials	Na.	652.3	Na.	311.8	Na.	623.9	Na.	1,096.0	Na.	537.9

---

[1] Tr. = less than 0.05 individuals or mg/m^3.

[2] Including for present purposes: HEMIPTERA - Mesoveliidae and Microveliidae; TRICHOPTERA - Hydroptilidae; DIPTERA - Tipulidae, Culicidae, Dixidae, and Empididae; COLEOPTERA - Elmidae, Dytiscidae, Halipidae, and Hydrophilidae; HYDRAZOA - Hydridae; and NEMATODA - Undetermined taxa.

[3] Including: PLECOPTERA - Capniidae; and TRICHOPTERA - Undetermined adults.

[4] Including for present purposes: COLLEMBOLA - Undetermined taxa and Sminthuridae; THYSANOPTERA - Tripidae; HEMIPTERA - Undetermined terrestrial taxa; HOMOPTERA - Aphididae and Undetermined taxa; COLEOPTERA - Staphylinidae; HYMENOPTERA - Chalcidoidea and formicidae; MALLOPHAGA - Undetermined taxa; ARANIEDA - Undetermined taxa; and TARDIGRADA - Undetermined taxa.

[5] Na. = Not applicable.

[6] Leaf litter was not included.

Trichopteran larvae of the genera Hydropsyche and Cheumatopsyche were scarce early in the study, but became more important later as a major component of biomass in benthic samples and relatively common taxa in drift. Glossosomatid trichopterans followed a similar trend. High biomass estimates for trichopterans, especially hydropsychids, typically resulted from presence of a few large individuals, rather than dense populations.

A large number of other animals were recorded in drift samples, some in small numbers or only occasionally, and others seasonally. Especially seasonal in abundance was the plecopteran Capnia frisoni, which was taken only in colder periods, and turbellarians that appeared in summer samples in benthos, but did not enter drift (Tables VI-7 - VI-8).

In paired samples of benthos and drift from Aravaipa Creek, 36 items were in the benthos. Twenty-six (72.2%) of these were nymphs, larvae, pupae, and non-emerging adults of aquatic insects, 7 (19.4%) were other aquatic invertebrates, and 3 (8.3%) were non-animal categories (algae, diatoms, and detritus). Drift sampling caught items of 66 categories, of which 27 (49.1%) were aquatic insects (nymphs, larvae, pupae, and non-emerging adults), 5 (9.1%) were emergent adults of aquatic taxa, 7 (12.7%) were other aquatic invertebrates, and 13 (23.6%) were invertebrates of terrestrial origin. Three (5.5%) were the non-animal components defined above.

4. Discussion

The dramatic influence of flooding on Aravaipa creek was equally as evident in aquatic invertebrates as it was with other features. Losses in a given flood ranged to near 99% of numbers of animals, yet recolonization was so rapid that within a few days substantial populations were again present.

Gray (1980) recorded an average of 86% loss in total numbers and 81% in biomass in creeks of the Sycamore Creek watershed, finding that flood intensity (rate of increase in discharge) was equally as important as flood magnitude (as measured by peak discharge) in causing reductions in the fauna. Thus smaller summer spates were as destructive as larger, more sustained, winter floods. Recovery time depended upon frequency of previous flooding in Sycamore Creek. After a single peak, density and biomass achieved pre-flood levels within 14 days. Repeated flooding resulted in longer periods for recovery, on the order of 5 to 7 weeks.

Sampling in Aravaipa Creek was not frequent enough to critically assess these factors, but relations of flood-frequency to time of recovery (Figs. VI-5 - VI-7) resembled those described and recovery after floods was almost equally as rapid (Figs. VI-8 - VI-9). Mechanisms whereby such faunas avoid destruction were clarified by Gray (1980), who demonstrated amazingly short generation times for many aquatic insect taxa in Sycamore Creek. Many species in that system reproduced continuously throughout the year and fulfilled their life cycles in less than 14 days, so that probability of all individuals being influenced by a given flood was negligible. Included were Baetis quilleri, Leptohypes packeri, Tricorythodes dimorphus, and Callibaetis montanus (Ephemeroptera), diverse Chironomidae, and Probezzia sp. (Ceratopogonidae). The corixid hemipteran Graptocorixa serrulata fulfilled its life cycle in 21 days. Most of these genera are also present in Aravaipa Creek (Table VI-5).

These insects therefore circumvent the problem of flooding by having adults present at all times, and oviposition in receding flood waters can result in mature larvae in as little as two weeks. Thus, under a "normal" regime of discharge in Aravaipa Creek, represented best by 1975 and 1976 (Fig.

VI-1), with late winter flooding, spring drought, summer spates, then autumn drought, depression of the fauna would be expected only when flood peaks were relatively close order, i.e. during summer rains. This was well represented in the data (Figs. VI-5 - VI-6). With sustained flooding, the strategy would be less effective, and populations would be expected to progressively decline, as occurred in 1977-78.

Decline in the benthic fauna also involves faunal change and depletion (Table VI-7). Late in the study essentially all but baetid mayflies, plecopterans, and a few chironomid dipteran larvae were absent. Trichopteran larvae were essentially gone after July 1977, and coleopterans, hemipterans, and odonates, were rare. These last groups include those identified by Gray as lacking short life cycles in the Sycamore Creek drainage, and he also demonstrated their extirpation after a period of sustained flood. Their slow recovery in Sycamore Creek was attributed to migration from the adjacent, perennial Verde River.

Quantitative data for tributaries are available only for the almost-perennial Turkey Creek (Table VI-9), but qualitative observations on other places pertain to recolonization of the mainstream of Aravaipa Creek and merit discussion if for no other reason than to stimulate other investigations. In "normal" years, most tributaries to Aravaipa Creek are dry, or at best intermittent, with water retained only in rock pools (tinajas). Even Turkey Creek dries to intermittent pools connected by short flowing reaches or maintained by underflow within sediments. The insect fauna of such habitats consists of odonate niaids (Libellulidae and Coenagrionidae), dytiscid beetles of the genera Deronectes, Laccophilus, the hydrophilid Tropisternus, and other numerous hemipterans (Abedus, Notonecta, Buenoa, and water striders -

Table VI-9. Average densities of benthic invertebrates in Turkey Creek. Graham County, Arizona, in different seasons, 1976-78; summer data precede spates in each instance. Number of samples are in parenthesis.

Taxa	Summer 1976	Winter 1976-77	Summer 1977	Winter 1978
EPHEMEROPTERA				
Baetis spp.	4	1755	---	190
Choroterpes sp.	36	43	24	---
Ephemerella sp.	---	6	---	---
Tricorythodes spp.	---	285	---	11
PLECOPTERA				
Capnia frisoni	---	26	---	151
TRICHOPTERA				
Hydropsychidae	7	22	---	19
Hydroptilidae	43	---	37	---
Limnephilidae	---	76	---	7
DIPTERA				
Chironomidae	560	1007	794	132
Simuliidae	---	646	---	11
Ceratopogonidae	---	81	---	11
Stratiomyidae	4	---	---	---
Ephydridae	---	22	---	6
HEMIPTERA				
Graptocorixa sp.	25	11	64	1
Abedus sp.	4	---	3	---
Ambrysus sp.	4	---	3	---
Veliidae	2	6	---	---
Gerridae	4	---	9	---
Pleidae	7	---	1	---
Notonectidae	7	---	9	---
Gelastocoridae	4	---	9	---
COLEOPTERA				
Hydrophilidae	11	5	19	---
Dytiscidae	441	54	364	20
Dryopidae	18	---	9	---
Elmidae	4	32	2	64
Haliplidae	201	---	---	---
ODONATA				
Libellulidae	29	---	17	---
Gomphidae	---	16	7	1
Coenagrionidae	7	---	19	---
Oligochaeta				
Undetermined spp.	47	54	91	17
TURBELLARIA				
Planariidae	14	---	9	---
GASTROPODA				
Physa sp.	20	---	32	---

Gerridae, Veliidae, and Pleidae), omnipresent chironomid dipterans, and rarely baetid mayflies. Filter feeders are hydropsychid trichopterans and simuliid dipterans are absent, as are other current-loving forms as riffle beetles (Elmidae). Insects occurring there also often inhabit shallow, temporary ponds resulting from rainfall accumulation, and are rarely abundant in flowing systems even when present. In winter, when permanent flow is present for a few weeks or months, trichopterans, various mayflies, plecopterans, diverse dipterans, and other groups characteristic of the mainstream of Aravaipa Creek colonize these waterways. In wet years, such as 1978, the fauna of normally-ephemeral canyons changes to resemble that of the mainstream in "normal" years, and temporary pond animals are absent. Thus, scour in the channel may extirpate species locally, but they colonize refugia in side canyons and from there re-invade when conditions in the master stream become more amenable. As side canyons cease to flow temporary ponds in the surroundings also dry, forcing movement of that fauna back to tinaja habitats, and a cycle is again complete.

It is obvious that seasonal abundance of most individual taxa in Aravaipa Creek reflect the overriding force of summer flooding (Fig. VI-10). This is especially evident in most substrate-surface dwellers as mayflies and certopogonid dipterans, and interstices- or burrow-dwellers such as chironomids, oligochaetes, and water mites (Acri). The former are free living, thus directly exposed to spates and the latter are subject to decimation as substrates are mobilized and scour proceeds. Riffle beetles (Elmidae) must have specializations that allows persistence through floods, but the mechanism is unknown. That animal showed no evidence of depletion with flooding (Fig. VI-10). The plecopteran Capnia frisoni occurred only in winter, and was

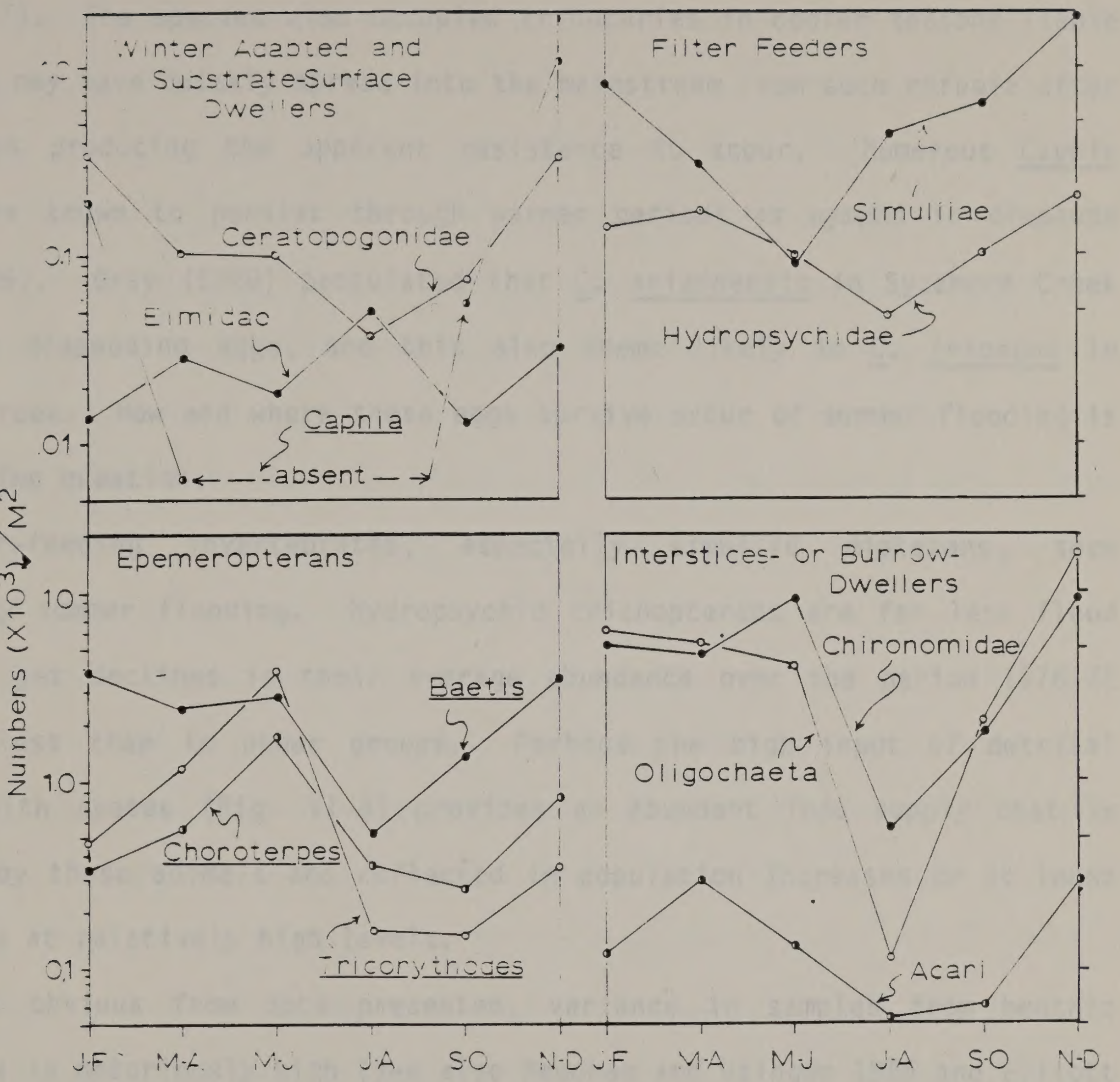

Figure VI-10. Abundance of selected aquatic invertebrates in Aravaipa Creek, Graham and Pinal counties, Arizona, 1975-78, computed as means of samples in two-month periods; see text for further explanation and discussion.

almost as abundant during flooding of 1977-78 as it was in preceding years (Table VI-7). The species also occupied tributaries in cooler seasons (Table VI-8), and may have quickly spread into the mainstream from such refugia after flood, thus producing the apparent resistance to scour. Numerous *Capnia* species are known to persist through warmer periods as nymphs in diapause (Hynes 1976). Gray (1980) postulated that *C. arizonensis* in Sycamore Creek did so as diapausing eggs, and this also seems likely in *C. friosoni* in Aravaipa Creek. How and where these eggs survive scour of summer flooding is an intriguing question.

Filter-feeding invertebrates, especially simuliid dipterans, seem enhanced by summer flooding. Hydropsychid trichopterans are far less flood resistant, yet declines in their average abundance over the period 1976-78 were far less than in other groups. Perhaps the high input of detrital material with spates (Fig. VI-4) provides an abundant food supply that is exploited by these animals and reflected in population increases or at least maintenance at relatively high levels.

As is obvious from data presented, variance in samples from benthic communities is notoriously high (see also Needham and Usinger 1956 and Elliott 1971), presumably as a result of heterogeneity of stream habitats joined with diversified life histories and behavior of faunal constituents. Drift of certain organisms (*i.e.* baetid mayflies) has, however, been demonstrated to be consistent and predictable, and proposed as another measure of invertebrate populations in streams, possibly more sensitive than direct sampling of benthos (Waters 1965, 1972). Mixing action of turbulence tends to suppress affects of heterogeneity.

Relationship between drift and standing crop of benthos at a given place is only a general one, especially if habitats upstream vary significantly from that at the point of sampling. Waters (1965) estimated on the basis of blocking a stream that organisms drifting at a given place originated no more than 50 to 60 m upstream. Comparisons of standing crops of benthos and drift at the Aravaipa Creek station was justified by similarity of habitats throughout the study reach and by lack of statistical differences in numbers and biomass at the station and another site immediately above (see Bruns 1977 and Bruns and Minckley 1980). In addition, sampling of drift and benthos were always taken about midway in a 60-m-long, uniform riffle, so that comparative integrity of data was maintained.

Invertebrates common to both drift and benthos included all important categories discussed before. Slightly more than 65% of drift (excluding non-animal components) was derived from benthos, and this rose to 75% when emerged adults of aquatic insects were included. Three of four items in drift of Aravaipa Creek were therefore autochthonous to the system. Of 32 benthic taxa recorded (again excluding the non-animal items), 23 (71.4%) drifted. Groups of benthic animals absent from drift included Libellulidae (dragon flies), Tabanidae (horse flies), Muscidae (house flies), Rhagoveliidae (water striders), Helicopsychidae and Limniphilidae (caddis flies), Corydalidae (hellgrammites), Hirudinea (leeches), and turbellarians (flatworms). Absence of all but the last from drift may generally be attributed to their rarity. Turbellarians appear to resist drifting in Aravaipa Creek.

Of organisms drifting, only baetid and tricorythid mayflies and chironomid dipteran larvae and pupae were present in all samples on all sampling dates. Numbers of those animals per cubic meter of water correlated roughly

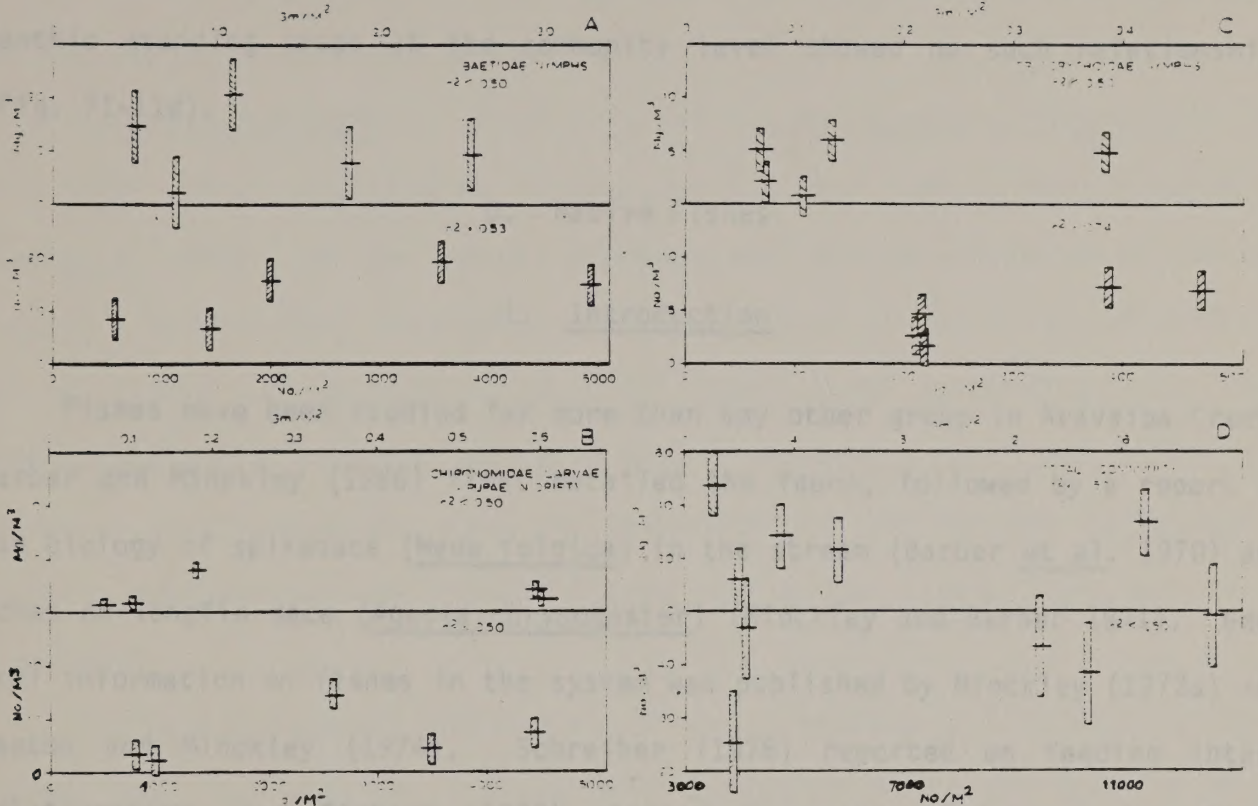

Figure VI-11. Weights and numbers of invertebrates/M^3 in drift compared with standing crop and biomass/M^2 in benthos.

with numerical standing crops estimated by benthic sampling in the same periods, but no such relationships existed between their weights in drift and those in benthos (Fig. VI-11a-c; $r^2 < 0.5$). Similar comparisons of drift and benthic standing crops at the community level showed no such relationships (Fig. VI-11d).

D. Native Fishes

1. Introduction

Fishes have been studied far more than any other group in Aravaipa Creek. Barber and Minckley (1966) first detailed the fauna, followed by a report on the biology of spikedace (Meda fulgida) in the stream (Barber et al. 1970) and notes on longfin dace (Agosia chrysogaster) (Minckley and Barber 1971). General information on fishes in the system was published by Minckley (1973a) and Deacon and Minckley (1974). Schreiber (1978) reported on feeding interrelationships, and Siebert (1980) studied movements of larger, long-lived species. Copies of the last two works are included herein as appendices E and F. Other information on the ichthyofauna has appeared in processed reports resulting from periodic surveys (Minckley 1972, 1973b; Schreiber 1975).

2. Distributional and Taxonomic Notes

All seven native fishes now occupying Aravaipa Creek were formerly more widespread and abundant in the Gila River system than they are today. All have suffered reductions in range, especially at lower elevations, as a result of water developments, desiccation, and interactions with introduced forms.

The two suckers, Sonoran sucker (Catostomus insignis) and desert mountain-sucker (Pantosteus clarki) remain relatively abundant and wide

ranging. Both occur from the canal systems of the Phoenix Metropolitan Area upstream in the Salt, Verde, and Gila drainages to maximum elevations of ca. 1,900 m (rarely to 2,000 m). Both species also are present in the upper parts of the Bill Williams River basin.

Catostomus insignis is intimately related to Catostomus benardini of the Rio Yaqui system, southeastern Arizona and northern Sonora, Mexico (Hendrickson et al. 1981), and the two may represent well-marked subspecies of the same taxon. Smith (1966) considered mountain suckers of the Virgin and Pluvial White rivers as conspecific with P. clarki, and synonymized the genus Pantosteus as a subgenus of Catostomus. Minckley (1973) and Siebert and Minckley (1981) disagreed with the synonymization and retained Pantosteus as valid; mountain-suckers of the Virgin and White rivers have yet to be restudied.

Sonoran suckers are inhabitants of pools, seeking cover beneath undercut banks, near boulders, or in stream-drifted debris during the day, but moving to shallows and rarely to riffles to feed at night. Desert mountain-suckers also inhabit pools when large, but are far more frequent in current on riffles and rapids when young. Adults typically move into swifter water to feed. Aravaipa Creek is about as small a stream as will support large populations of these two fishes. Both tend to be more abundant in larger creeks and smaller rivers, and neither persists in Arizona impoundments for more than a few years.

Longfin dace, one of the few fishes adapted for life in small, hot, low-desert streams in the American Southwest (Minckley and Barber 1971), ranges from at least the Rio Fuerte Basin, Sinaloa, Mexico, northward to the Bill Williams River drainage of Arizona (Minckley 1980). In the Gila River system

its altitudinal range resembles that of the suckers just discussed, but in New Mexico it has been taken at elevations of almost 2,300 m, and in coastal rivers of Mexico the species occurs near sea level (Hendrickson *et al*. 1981). Longfin dace swim actively over moving sand bottoms in runs of desert streams, but as large adults tend to move into deeper places along banks. The fish rarely occurs in swift water, but conversely seems to avoid conditions where currents are totally absent.

Speckled dace (*Rhinichthys osculus*) is near the lower altitudinal limit of its range in Aravaipa Creek. It formerly occurred as low as *ca*. 350 m in large streams such as the Salt River at Tempe, but now is generally above 1,400 m, and reaches its greatest abundance higher than 1,800 m. *Rhinichthys osculus* is the most widespread species of fish in Western North America, ranging west of the Rocky Mountains from Oregon south to the Gila River basin, and occupying many isolated drainages within the Great Basin deserts (Hubbs and Miller 1948, Hubbs *et al*. 1974). As might be expected from this vast geographic range that results in pronounced isolation of numerous populations, a myriad of morphological forms has evolved. The form in Aravaipa Creek represents the nominal subspecies, *R*. *o*. *osculus*, and as such is one of only a few remaining populations of that taxon. Remnant populations occur elsewhere only in Cave Creek, Chiricahua Mountains, and Sonoita Creek, near Patagonia, Santa Cruz County. Populations formerly in Babacomari Creek (the type locality), San Pedro River, and upper Santa Cruz River, now are gone. Speckled dace resembles longfin dace in its habitat requirements, but tends to live in swifter water over gravelly substrates. Large adults often are in swifter water over gravelly substrates. Large adults often are in deeper runs and flowing parts of pools, and typically associated with cover.

The loach minnow, Tiaroga cobitis, is endemic to the Gila River basin. This small species persists as a relatively large population in Arizona only in Aravaipa Creek. It was recently taken (1978) from the Blue River system by Arizona Game and Fish Department personnel, but has not otherwise been recorded since the late 1960s from elsewhere in the state. Populations persist, however, in the upper Gila River drainage in New Mexico (Paul Turner, New Mexico State University, personal communication). Loach minnows live on shallow, gravel/rubble-bottomed riffles, typically in association with beds of filamentous algae such as Cladophora glomerata.

Meda fulgida, the spikedace, is the second Gila River endemic that occupies Aravaipa Creek. As with the loach minnow, this species has become rarer in Arizona in the past few years, with confirmed populations occurring only in Aravaipa and in the Verde River, Yavapai County, near the inflow of Sycamore Creek (C. O. Minckley collection, 1980). The species formerly occurred from Tempe, Arizona, upstream throughout the Gila River basin to an elevation of ca. 1,800 m. This species occupies flowing pools, and generally is in water less than a meter deep over sand, gravel, or mud bottoms. Concentrations often are encountered at the downstream ends of riffles or in eddies near the upper ends of pools. Large groups are occasionally in relatively shallow water over gravel bottoms where currents are laminar in nature; turbulent areas seem generally avoided.

Roundtail chub, Gila robusta, is the largest minnow in Aravaipa Creek, ranging to a maximum of 38.5 cm total length. This fish shares a high degree of morphological variability with speckled dace. The population in Aravaipa Creek was referred by Rinne (1976) to G. r. grahami, a form somewhat intermediate between G. r. robusta and the Gila chub, G. intermedia. Roundtail

chub range from Sinaloa, Mexico, to the uppermost Colorado River basin. Gila r. grahami is distributed in the uppermost Gila River basin, mostly in New Mexico (where it is becoming exceedingly rare; LaBounty and Minckley 1972), southwest to Aravaipa Creek, then north to tributaries of the Verde River. Populations in the little Colorado River also were referred to G. r. grahami (Rinne 1976), but the fish is not now known to persist in that drainage, so no recent information is available.

Roundtail chubs are characteristic of pools in intermediate to large streams. The species is secretive and closely associated with the largest, most permanent, and deepest water in a given reach of stream. One may often sample an extensive area finding no chubs, then suddenly discover a concentration of the fish in such a special place. Chubs swim rapidly from place to place, and move long distances (Siebert 1980). They are known to move into relatively swift chutes and eddies, presumably to feed.

3. Relative Abundance

Figures for relative abundance of fishes are subject to considerable error. Collectors vary in efficiency, and many samples from Aravaipa Creek were made by beginning students in fisheries biology, a less-than-formidable sampling crew even when under strict supervision. Sampling devices also vary in characteristics and efficiency. Seines with meshes larger than 6.3 mm (bar measure) will allow a large percentage of loach minnows and spikedace to pass through. Seining with various meshes in Aravaipa Creek in 1976-77 produced 81.3±11.4% as many fishes as was taken by electrofishing in the same places (range 62.0 - 93.8%), but only 63.1±14.9% of biomass (range 37.5 - 71.1%). Seines were least effective in catching larger fishes and benthic species such

as mountain-sucker and loach minnow. Small and moderate-sized fishes and species living in mid-water habitats were thus selected for. Conditions also may vary, with swift currents and high turbidities in times of flood inhibiting efficiency of any collecting efforts.

With these facts in mind I constructed Table VI-10 and Figure VI-12 from records available in the following sources: field notes of James R. Simon for 1943 and Robert R. Miller for 1950, both on file at the University of Michigan Museum of Zoology; field notes of Elena T. Arnold for 1963, on file at Arizona State University; recalculation of data published by Barber and Minckley (1966); field notes of my own, W. E. Barber, and D. C. Williams, and collections at Arizona State University for 1966-1970; recalculation of data in processed reports to the Bureau of Land Management and Defenders of Wildlife (Minckley 1972, 1973b, Schreiber 1975) for 1972-74; personal field notes and collections for 1973-75 and 1979; and data from the present study for 1976-78. Samples prior to 1974 were generally made by seines and after that year represent composites of seining and electrofishing collections.

Patterns of abundance of fishes within Aravaipa Creek are remarkably consistent (Table VI-10, Fig. VI-12). When direct comparisons are available, longfin dace are almost always most abundant downstream, below Aravaipa Canyon, and least abundant within the canyon. Speckled dace averaged twice as abundant above the canyon as within it, and rarely were present downstream, and loach minnow also tended to be most common in the uppermost segment. Sonora sucker, desert mountain-sucker, roundtail chub, and spikedace all tended to be most abundant within the canyon segment, but on the average were more abundant upstream when compared with lowermost reaches. As is to be detailed later, large fishes such as suckers and the chub move extensively in

Table VI-10. Relative abundance in percent of native fishes in Aravaipa Creek, Graham and Pinal counties, Arizona; hybrids and introduced species excluded.

Taxa	1943	1950	1963	1964	1965	1966	1967	1969	1970	1972	1973	1974	1975	1976	1977	1978	1979	Mean	Range
Stations above Aravaipa Canyon																			
Agosia chrysogaster	----	----	----	50.0		26.7	----	47.5	51.1	55.6	87.0	81.5	79.9	54.8	51.9	40.7	33.3	55.1	26.7 - 87.0
Rhinichthys osculus	----	----	----	1.0		4.1	----	3.1	2.9	0.3	5.5	3.5	4.7	16.5	21.3	20.7	19.4	8.6	0.3 - 21.3
Meda fulgida	----	----	----	5.0		1.9	----	0.7	1.3	0.3	0.0	11.5	1.2	2.2	1.0	1.7	0.9	2.3	0.0 - 11.5
Gila robusta	----	----	----	0.0		4.3	----	5.4	2.7	0.0	0.0	0.0	2.3	1.9	3.5	1.0	11.7	2.7	0.0 - 11.7
Tiaroga cobitis	----	----	----	4.0		5.2	----	6.0	7.4	15.8	0.0	0.3	0.4	0.9	1.1	0.8	2.1	4.1	0.0 - 15.8
Pantosteus clarki	----	----	----	32.5		31.9	----	23.4	30.7	16.3	0.0	3.0	9.1	11.4	13.2	10.9	11.5	16.3	0.0 - 32.5
Catostomus insignis	----	----	----	7.5		26.0	----	13.9	3.9	11.7	0.0	0.5	2.2	10.3	8.0	24.2	21.1	10.9	0.0 - 26.0
Within Aravaipa Canyon																			
Agosia chrysogaster	----	31.7	----	35.1		23.9	27.3	31.4	40.6	29.9	27.0	35.6	22.3	31.8	11.4	9.5	7.0	26.6	7.0 - 40.6
Rhinichthys osculus	----	5.5	----	0.0		8.2	4.1	2.3	1.0	0.0	5.5	0.0	4.1	6.5	9.7	11.4	7.2	4.3	0.0 - 11.4
Meda fulgida	----	0.0	----	18.6		16.4	11.4	18.7	9.5	6.9	28.0	18.6	11.1	17.0	9.3	7.4	10.4	13.1	0.0 - 28.0
Gila robusta	----	0.0	----	2.8		5.1	9.2	3.4	6.7	11.1	7.6	6.0	3.3	4.0	9.0	11.1	9.8	6.4	0.0 - 11.1
Tiaroga cobitis	----	14.6	----	0.0		3.3	2.1	11.9	0.8	3.4	0.0	0.4	1.4	0.7	3.1	1.4	0.9	3.2	0.0 - 14.6
Pantosteus clarki	----	35.5	----	25.5		29.5	30.0	23.8	29.8	24.9	21.5	8.4	36.1	25.4	39.1	41.4	49.1	29.8	8.4 - 39.1
Catostomus insignis	----	12.7	----	18.0		22.0	15.9	8.5	11.6	23.8	9.1	29.2	11.7	14.6	18.4	17.8	15.6	16.6	8.5 - 29.2
Below Aravaipa Canyon																			
Agosia chrysogaster	74.5	----	97.2	97.5		81.9	83.5	88.7	83.2	82.0	----	70.0	73.5	78.1	60.2	50.4	55.3	76.7	50.4 - 97.5
Rhinichthys osculus	0.0	----	0.0	0.0		0.0	0.0	0.0	0.0	0.0	----	0.0	0.0	0.0	0.3	0.0	1.0	0.1	0.0 - 1.0
Meda fulgida	0.0	----	0.0	0.0		3.1	1.1	0.3	0.9	1.3	----	1.0	1.4	3.8	5.1	3.3	6.1	2.0	0.0 - 6.1
Gila robusta	7.2	----	0.0	0.0		1.0	1.7	2.0	0.3	0.0	----	4.0	1.0	0.2	0.8	0.2	2.6	1.5	0.0 - 7.2
Tiaroga cobitis	0.7	----	0.0	0.0		2.3	0.8	0.3	0.9	1.9	----	0.0	5.7	0.7	0.8	0.1	1.0	1.1	0.0 - 5.7
Pantosteus clarki	12.4	----	2.6	1.3		10.9	9.7	6.7	11.3	12.6	----	18.0	13.9	12.4	28.1	32.1	23.7	14.0	1.3 - 32.1
Catostomus insignis	5.2	----	0.2	1.3		0.8	3.2	2.0	3.4	2.2	----	7.0	4.5	4.8	5.7	13.9	10.3	4.6	0.2 - 13.9

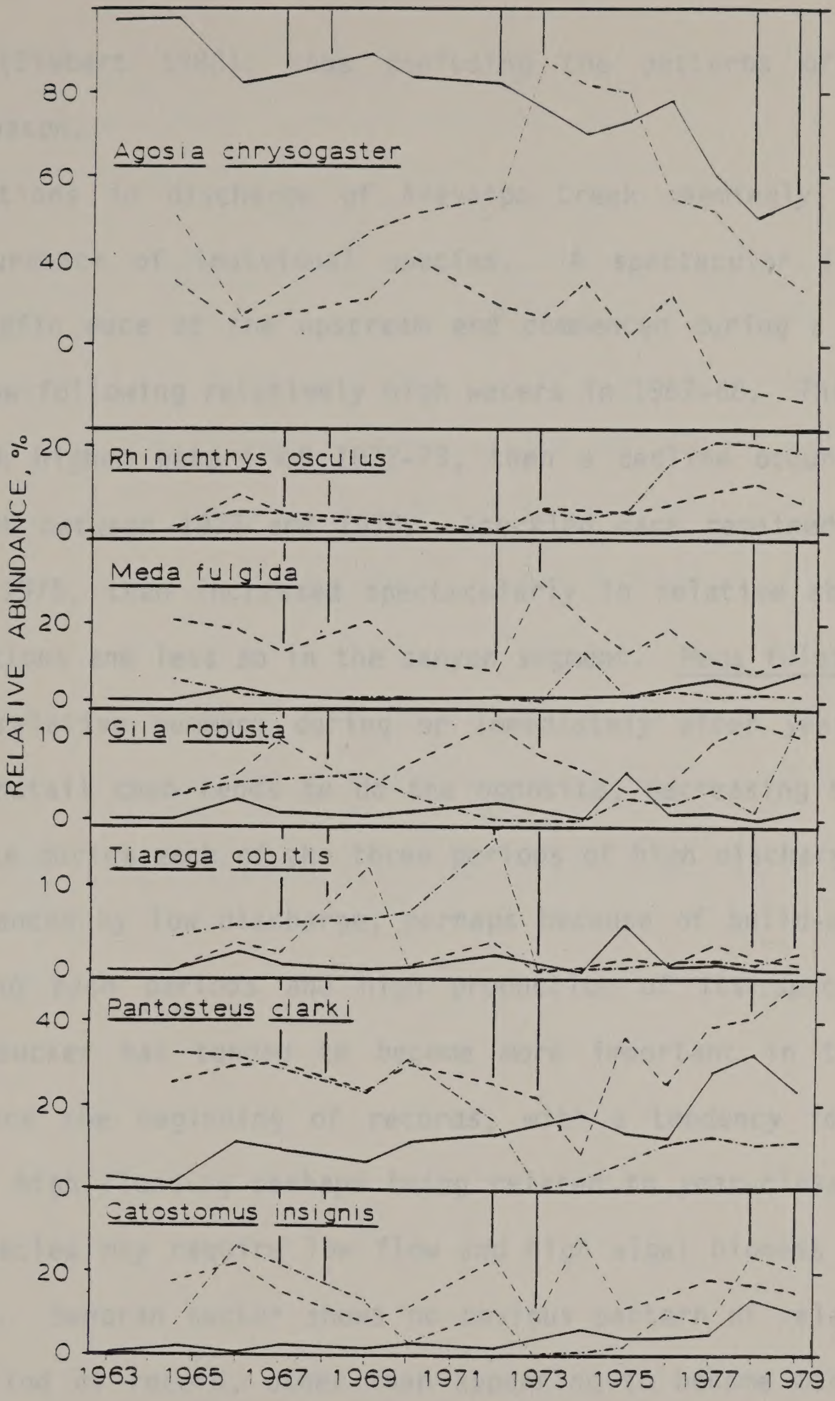

Figure VI-12. Relative abundance of native fishes in Aravaipa Creek, Graham and Pinal counties, Arizona, 1963-79; based upon data in Table VI-10. Vertical lines denote years of relatively high water yield in period of record (1966-79) from U.S. Geological Survey data.

Aravaipa Creek (Siebert 1980), thus confusing the patterns of abundance depending upon season.

Major variations in discharge of Aravaipa Creek seemingly has little influence on abundance of individual species. A spectacular increase in abundance of longfin dace at the upstream end commenced during a protracted period of low flow following relatively high waters in 1967-68. This increase continued through higher waters of 1972-73, then a decline occurred in the period of drought between 1973 and 1978. Speckled dace remained rare from 1965-66 through 1975, then increased spectacularly in relative abundance at the upstream stations and less so in the canyon segment. Meda fulgida appears to increase in relative numbers during or immediately after years of high water yield, roundtail chub tends to do the opposite, decreasing slightly in relative abundance during each of the three periods of high discharges. Loach minnow seems enhanced by low discharge, perhaps because of build-up of dense algal beds during such periods and high production of its special foods. Desert mountain-sucker has tended to become more important in the overall fauna almost since the beginning of records, with a tendency for declines after periods of high flooding perhaps being related to year-class strength; young of that species may require low flow and high algal biomass to survive in large numbers. Sonoran sucker shows no obvious pattern of relative abundance in the period of record, other than appearing to become more abundant within the overall fauna.

To further examine significance of relative abundance changes, data for 1976-78 were converted to $\log_{10} + 1$ to normalize non-random distributions. When treated in this manner (Table VI-11), there are no significant differences in up- to downstream relative abundance of most species within the

Table VI-11. Relative numerical abundance ($\log_{10}$ + 1 of percentages ± one standard error of the mean) of fishes above, within, and below Aravaipa Gorge, Aravaipa Creek, Graham and Pinal counties, Arizona, 1976-78.

Taxa	Above	Within	Below
Agosia chrysogaster	1.394 ± 0.628	2.301 ± 0.385	2.404 ± 0.622
Rhinichthys osculus	2.155 ± 0.2580	1.722 ± 0.608	1.004 ± 0.019
Meda fulgida	1.244 ± 0.380	1.814 ± 0.557	1.602 ± 0.557
Gila robusta	1.147 ± 0.314	1.322 ± 0.520	1.282 ± 0.390
Tiaroga cobitis	1.231 ± 0.381	1.308 ± 0.440	1.019 ± 0.070
Pantosteus clarki	1.945 ± 0.659	2.322 ± 0.443	2.416 ± 0.299
Catostomus insignis	1.339 ± 0.541	1.837 ± 0.261	1.687 ± 0.610
catostomid hybrid	1.005 ± 0.020	1.031 ± 0.123	1.015 ± 0.066

system (as indicated by broad overlap of standard errors). Rhinichthys osculus is significantly more abundant upstream than downstream, but such relations do not hold for other species. The common fishes, longfin dace and mountain-sucker, obviously are far more common than rarer species, but often not significantly so when standard errors are considered. Variance therefore over-rides trends if one adheres to a strict, statistical interpretation. Other measures of relative abundance within the system for the period of intensive study, 1976-78, are in Tables VI-12 - VI-13.

4. Standing Crops

a. Methodology. Electrofishing was used to estimate standing crops of fishes in Aravaipa Creek. Equipment consisted of a 110-volt, 1200-watt, generator and hand-held electrodes. Segments of stream were blocked up- and downstream by seines, and the reach was repeatedly electrofished until all fishes were removed. They were then counted and weighed, and data were converted to numbers or weight per m^2. Ninty-nine percent, or more, of total numbers and biomass obtained in 6 to 10 "passes" through three separate stream segments was taken in the first three passes (Table VI-14), and that number was used throughout the study. Larger fishes (roundtail chub, mountain-sucker, and Sonora sucker) were most susceptible to the electrical field, and small, bottom-dwelling fishes (especially loach minnow and young mountain-suckers) were least effectively sampled. Only in the largest pools was the electrofishing unit obviously ineffective, where deeper water and often turbidity hampered recovery of stunned animals.

b. Results. Mean numbers of fishes in various seasons and stream segments ranged from 0.13 to $5.99/m^2$, about half of which were longfin dace

Table VI-12. Frequency of occurrence (%) of fishes above, within, and below Aravaipa Gorge, Aravaipa Creek, Graham and Pinal counties, Arizona, 1976-78.

Taxa	Above	Within	Below	Over-all
Agosia chrysogaster	93.3	100.0	94.4	95.9
Rhinichthys osculus	93.3	68.8	5.6	53.1
Meda fulgida	40.0	81.3	61.1	61.2
Gila robusta	20.0	68.8	50.0	47.0
Tiaroga cobitis	73.3	62.5	22.2	51.0
Pantosteus clarki	86.7	93.8	100.0	93.9
Catostomus insignis	67.7	93.8	77.7	79.9
catostomid hybrids	6.7	6.3	5.6	6.2

Table VI-13. Percentage abundance of fish species in collections in which they occurred above, within, and below Aravaipa Gorge, Aravaipa Creek, Graham and Pinal counties, Arizona, 1976-78.

Taxa	Above	Within	Below	Over-all
Agosia chrysogaster	46.6 ± 30.4	26.7 ± 17.8	49.5 ± 28.3	40.9 ± 26.6
Rhinichthys osculus	27.7 ± 22.3	17.8 ± 19.6	1.2 ± 0.0	22.5 ± 20.3
Meda fulgida	4.3 ± 3.2	14.6 ± 12.5	12.7 ± 9.7	11.8 ± 9.6
Gila robusta	5.9 ± 2.8	8.0 ± 12.7	5.1 ± 5.2	6.6 ± 8.5
Tiaroga cobitis	3.0 ± 2.7	6.0 ± 8.4	3.8 ± 4.9	4.3 ± 5.3
Pantosteus clarki	22.9 ± 23.1	31.1 ± 16.9	31.4 ± 17.7	28.9 ± 19.0
Catostomus insignis	7.9 ± 8.6	12.2 ± 6.7	13.8 ± 18.8	11.7 ± 9.8
catostomid hybrids	1.2 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	0.5 ± 0.6

Table VI-14. Percentages of total numbers (above) and weights (below) of fishes taken in consecutive "passes" of electrofishing apparatus in Aravaipa Creek, Graham and Pinal counties, Arizona, based upon sampling of three separate stream segments.

Species	"Pass" Number 1	2	3	4	5	6-10
Agosia chrysogaster	90.0	7.9	1.7	0.1	----	0.3
	92.2	6.1	1.5	Tr.[1]	----	0.3
Rhinichthys osculus	86.8	11.3	----	0.6	----	1.3
	89.2	9.3	----	0.6	----	0.9
Meda fulgida	88.7	2.4	8.1	----	0.8	----
	94.3	1.6	3.2	----	1.0	----
Gila robusta	100.0	----	----	----	----	----
	100.0	----	----	----	----	----
Tiaroga cobitis	53.8	30.8	7.7	----	7.7	----
	20.0	60.0	8.0	----	12.0	----
Pantosteus clarki	91.0	6.6	1.7	0.3	0.3	0.1
	92.4	5.4	0.7	0.5	0.6	0.4
Catostomus insignis	82.7	14.0	2.6	0.7	----	----
	93.8	2.6	3.0	0.6	----	----
Total numbers and	3,224	289	69	7	4	8
weights (gm)	10,768.8	453.0	233.1	55.9	28.6	21.4
Over-all	89.5	8.0	1.9	0.2	0.1	0.2
Percentages	93.2	3.9	1.9	0.5	0.2	0.2

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[1] Tr. = less than 0.05

(34.5 to 56.3%; Table VI-15). About 20% consisted of desert mountain-suckers (11.2 to 36.3%), 15% were speckled dace (4.5 to 30.9%), and the other species comprised less than 10% each. Fishes were most abundant in summer and autumn, reflecting recruitment of young in spring. Fishes were markedly less abundant within Aravaipa Canyon in spring periods than at other times, but were rather uniformly distributed in summer and winter.

Comparison of populations of fishes in contrasting summer and winter seasons (Table VI-15) reveals marked differences in species composition in various stream segments. Longfin dace were absent or essentially so within the canyon segment in winter and spring, but made up about 40% of all fishes in that area in summer and autumn. Speckled dace were concentrated upstream in spring, then spread downstream into the canyon in other seasons. The chub and suckers tended to concentrate in the canyon in summer and appeared to disperse upstream in summer. Loach minnow and spikedace were consistently rare, and few generalizations are obvious from their obsolute or relative abundance.

Biomass of total fishes in Aravaipa Creek is spectacularly high at some times of year, and vary significantly in different segments of the stream (Table VI-16). Total weights were greater above and below the canyon than within it in spring, autumn, and winter, but were far greater within the canyon than elsewhere in summer (Table VI-17). This was a direct result of movements of large fishes, principally suckers, into the canyon reach during warmer summer months, and out of that reach when temperatures ameliorated in winter (Siebert 1980).

Few data are available on standing crops of fishes in Southwestern streams. Clarkson (1980) reviewed a substantial amount of literature, and his

Table VI-15. Numbers and relative abundance in percent of fishes/m^2 in electrofishing samples from Aravaipa Creek, Arizona, 1976-78; n + number of samples; area = total area samples (m^2).

Season[1] and Taxon	Above Canyon		Within Canyon		Below Canyon		Totals	
	No.	%	No.	%	No.	%	No.	%
Spring	n = 4, area 490		n = 2, area 161		n = 3, area 452		n = 9, area 1,093	
Agosia chrysogaster	0.77	56.6	----	----	0.46	57.6	0.54	56.3
Rhinichthys osculus	0.27	19.9	----	----	----	----	0.12	12.5
Meda fulgida	0.03	2.2	0.02	17.8	0.03	3.8	0.03	3.1
Gila robusta	0.01	0.7	----	----	Tr.[2]	0.5	0.01	1.0
Tiaroga cobitis	0.03	2.2	----	----	Tr.	0.5	0.02	2.1
Pantosteus clarki	0.16	11.8	0.09	64.2	0.24	30.1	0.18	18.8
Catostomus insignis	0.08	5.9	0.02	17.8	0.06	7.5	0.06	6.3
Totals	1.35	99.5	0.13	99.9	0.79	100.0	0.96	100.1
Summer	n = 5, area 432		n = 8, area 703		n = 5, area 456		n = 18, area 1,591	
Agosia chrysogaster	0.43	38.7	0.44	36.3	1.23	67.5	0.66	49.2
Rhinichthys osculus	0.43	38.7	0.08	6.6	----	----	0.15	11.2
Meda fulgida	0.01	0.9	0.09	7.4	0.10	5.5	0.07	5.2
Gila robusta	----	----	0.07	5.8	0.04	2.2	0.04	3.0
Tiaroga cobitis	0.03	2.7	0.03	2.5	Tr.	0.1	0.02	1.5
Pantosteus clarki	0.19	17.1	0.36	29.7	0.25	13.7	0.28	20.9
Catostomus insignis	0.02	1.8	0.14	11.6	0.20	11.0	0.12	8.9
catostomid hybrid	----	----	Tr.	0.1	----	----	Tr.	Tr.
Totals	1.01	99.9	1.21	100.0	1.82	100.0	1.34	99.9

Table VI-15. Concluded.

Season and Taxon	Above Canyon		Within Canyon		Below Canyon		Totals	
	No.	%	No.	%	No.	%	No.	%
Autumn	n = 3, area 316		n = 4, area 773		n = 3, area 449		n = 10, area 1,538	
Agosia chrysogaster	2.94	49.1	0.23	43.4	0.81	55.5	0.96	51.1
Rhinichthys osculus	2.83	47.2	0.04	7.5	----	----	0.58	30.9
Meda fulgida	----	----	0.07	13.2	0.04	2.7	0.05	2.7
Gila robusta	----	----	0.01	1.9	----	----	0.01	0.5
Tiaroga cobitis	0.02	0.3	0.01	1.9	0.01	0.7	0.01	0.5
Pantosteus clarki	0.14	2.3	0.13	24.5	0.49	33.6	0.21	11.2
Catostomus insignis	0.06	1.0	0.04	7.5	0.11	7.5	0.06	3.2
Totals	5.99	99.9	0.53	99.9	1.46	100.0	1.88	100.1
Winter	n = 4, area 152		n = 6, area 492		n = 9, area 981		n = 19, area 1,625	
Agosia chrysogaster	0.30	15.7	0.06	5.8	0.56	55.7	0.38	34.5
Rhinichthys osculus	0.06	3.1	0.14	13.5	Tr.	0.2	0.05	4.5
Meda fulgida	0.10	5.2	0.11	10.6	0.04	4.0	0.07	6.4
Gila robusta	0.11	5.8	Tr.	0.4	0.01	1.0	0.02	1.8
Tiaroga cobitis	0.03	1.6	0.24	23.2	Tr.	0.2	0.08	7.3
Pantosteus clarki	1.09	57.1	0.37	35.8	0.31	30.8	0.40	36.3
Catostomus insignis	0.21	11.0	0.11	10.6	0.08	8.0	0.10	9.2
catostomid hybrid	0.01	0.5	----	----	Tr.	0.2	Tr.	0.2
Totals	1.91	100.0	1.03	99.9	1.00	100.1	1.10	100.1

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[1] Defined as recommended by Siebert (1980) on the basis of thermal characteristics of Aravaipa Creek: spring = April; summer = May-September; autumn = October, and winter = November-March.

[2] Tr. = less than 0.05.

Table VI-16. Weights and relative abundance in percent of weight/m^2 in electrofishing samples from Aravaipa Creek, Arizona, 1976-78; numbers of samples and total areas sampled are in Table VI-15, and totals for each season are in Table VI-17.

Season[1] and Taxon	Above Canyon		Within Canyon		Below Canyon		Totals	
	No.	%	No.	%	No.	%	No.	%
Spring								
Agosia chrysogaster	1.98 g	14.9	----	----	1.47	20.0	1.50	15.8
Rhinichthys osculus	0.48	3.6	----	----	----	----	0.22	2.3
Meda fulgida	0.08	0.6	0.07	2.1	0.08	1.1	0.08	0.8
Gila robusta	1.28	9.6	----	----	0.52	7.1	0.79	8.3
Tiaroga cobitis	0.09	0.7	----	----	0.01	0.1	0.04	0.4
Pantosteus clarki	3.38	25.4	1.83	54.3	2.12	28.8	2.66	27.9
Catostomus insignis	6.04	45.3	1.47	43.6	3.16	42.9	4.23	44.4
Summer								
Agosia chrysogaster	0.68	34.7	0.77	2.9	2.94	26.5	1.37	8.8
Rhinichthys osculus	0.82	41.8	0.18	0.7	----	----	0.30	2.1
Meda fulgida	0.01	0.5	0.16	0.6	0.11	1.0	0.10	0.6
Gila robusta	----	----	2.90	10.8	0.65	5.8	1.47	9.5
Tiaroga cobitis	0.05	2.6	0.06	0.2	Tr.[2]	Tr.	0.04	0.3
Pantosteus clarki	0.27	13.8	10.67	39.8	4.26	38.3	6.01	38.6
Catostomus insignis	0.13	6.6	12.00	44.8	3.15	28.3	6.24	40.1
catostomid hybrid	----	----	0.04	0.1	----	----	0.02	0.1

Table VI-16. Concluded.

Season[1] and Taxon	Above Canyon		Within Canyon		Below Canyon		Totals	
	No.	%	No.	%	No.	%	No.	%
Autumn								
Agosia chrysogaster	5.01	46.2	0.44	6.9	1.30	8.7	1.63	16.6
Rhinichthys osculus	3.02	27.9	0.97	1.1	----	----	0.66	6.7
Meda fulgida	----	----	0.12	1.9	0.05	0.3	0.07	0.7
Gila robusta	----	----	0.37	5.8	----	----	0.19	1.9
Tiaroga cobitis	0.02	0.2	0.01	0.2	0.02	0.1	0.01	0.1
Pantosteus clarki	2.35	21.7	2.22	34.6	8.39	56.2	4.05	41.3
Catostomus insignis	0.44	4.1	3.18	49.6	5.16	34.6	3.19	32.6
Winter								
Agosia chrysogaster	0.12	0.2	0.35	1.9	1.62	7.6	1.10	4.5
Rhinichthys osculus	0.10	0.2	0.26	1.4	0.01	Tr.	0.09	0.4
Meda fulgida	0.16	0.2	0.19	1.0	0.17	0.3	0.11	0.4
Gila robusta	6.91	10.5	0.13	0.7	0.83	3.9	1.19	4.8
Tiaroga cobitis	0.06	0.1	0.55	2.9	0.01	Tr.	0.17	0.7
Pantosteus clarki	38.87	59.3	9.51	50.3	12.14	57.1	13.84	56.1
Catostomus insignis	18.58	28.4	7.91	41.9	6.60	31.0	8.12	32.9
catostomid hybrid	0.71	1.1	----	----	Tr.	Tr.	0.07	0.3

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[1] Defined as recommended by Siebert (1980) on the basis of thermal characteristics of Aravaipa Creek: spring = April; summer = May-September; autumn = October; and winter = November-March.

[2] Tr. = less than 0.05.

Table VI-17. Standing crops of total fishes (g/m^2 followed by one standard error of the mean) above, within, and below Aravaipa Gorge, Arizona, 1976-78; number of samples followed by range in parentheses.

Seasons[1]	Above	Within	Below
Spring	13.33 ± 4.76 (4, 6.43 - 21.16)	3.42 ± 2.04 (2, 1.99 - 4.87)	7.36 ± 1.85 (3, 5.26 - 9.41)
Summer	1.96 ± 1.11 (5, 0.76 - 5.80)	26.78 ± 29.57 (8, 9.31 - 99.17)	11.11 ± 2.47 (5, 8.06 - 15.41)
Autumn	10.84 ± 4.33 (3, 6.71 - 15.36)	6.41 ± 2.68 (4, 3.27 - 9.84)	14.92 ± 7.95 (3, 6.89 - 22.78)
Winter	65.51 ± 41.26 (4, 32.64 -120.56)	18.90 ± 4.24 (6, 12.87 - 24.31)	21.28 ± 6.05 (9, 9.43 - 23.17)
Totals	20.99 ± 27.55 (16, 0.76 -120.56)	21.01 ± 20.62 (20, 1.99 - 99.17)	14.40 ± 9.92 (20, 5.26 - 23.17)

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[1] Defined as recommended by Siebert (1980) on the basis of thermal characteristics of Aravaipa Creek: spring = April; summer = May-September; autumn = October; and winter = November-March.

biomass comparisons from various studies are contrasted with data from Aravaipa Creek in Table VI-18. Only data from hot-desert sites, Bonita Creek, eastern Arizona (Clarkson 1980), Eagle Creek, eastern Arizona (Minckley and Clarkson 1979), and Tecopa Bore, California (Naiman 1974) are comparable to those from Aravaipa Creek. Mean biomass in Aravaipa Creek, 14.4 to 21.0 g/m^2 depending upon the stream section (Table VI-17), was less than half that recorded in Bonita Creek (46.7 g/m^2; Clarkson 1980), but is nonetheless comparable to Naiman's (1974) estimate of an annual standing crop of pupfishes at 17.8 g/m^2 (converted from kilocalories/m^2), and higher than many of the maxima reported from other streams (Table VI-18).

Numbers of individuals ranged between 0.3 and 50.8/m^2 in Bonita Creek and 0.4 to 16.4/m^2 in Eagle Creek, again quite similar to the range of 0.6 to 16.9/m^2 in Aravaipa Creek. Naiman (1974) separated pupfish (Cyprinodon nevadensis) that he studied into size classes, reporting juveniles at densities of 0 to 47/m^2, young adults as 8 to 148/m^2, and large adults at 2 to 17/m^2.

5. Foods and Feeding

Schreiber (1978) detailed foods and feeding interrelations of fishes in Aravaipa Creek and his report is included as Appendix E. Food habits of the seven native species of fishes were examined over a 13-month period. Availability of foods to the fishes was estimated by sampling benthic communities and stream drift. Three trophic patterns were present: herbivory by the mountain-sucker; omnivory by longfin dace; and carnivory by the remaining five species. Ephemeropteran nymphs were the predominant food of the carnivorous fishes, and of the omnivore, and were the dominant invertebrate in both

Table VI-18. Standing crops (g/m^2) of fishes in desert and non-desert streams. The symbol "*" denotes data approximated from some other measure of standing crop; from Clarkson (1980) with modifications.

Localities	Species Composition	g/m^2	Sources
Aravaipa Creek, AZ	*Agosia chrysogaster*, *Rhinichthys osculus*, *Meda fulgida*, *Gila robusta*, *Tiaroga cobitis*, *Pantosteus clarki*, *Catostomus insignis*	0.8-120.6	Present study
Bonita Creek, AZ	*A. chrysogaster*, *R. osculus*, *P. clarki*, *C. insignis*	0.3-166.8 0.4-149.9	Minckley and Clarkson (1979) Recalculated by Clarkson (1980)
Eagle Creek, AZ	*Cyprinus carpio*, *Notropis lutrensis*, *Pimephales promelas*, *A. chrysogaster*, *G. robusta*, *P. clarki*, *C. insignis*, *Ictalurus melas*, *I. natalis*, *I. punctatus*, *Pylodictis olivaris*	0.7-104.3	Minckley and Clarkson (1979)
Tecopa Bore, CA	*Cyprinodon nevadensis*	4.2- 95.8*	Naiman 1974
Seven Springs, AZ	*A. chrysogaster*, *R. osculus*, *Gila intermedia*	0.8- 9.6	Rinne 1975
Sagehen Creek, CA	*A. trutta*, *S. gairdneri*,	2.4- 6.4	Gard and Seegrist 1972
Deer Creek, OR	*Oncorhynchus kisutch*	0.3- 5.5	Chapman 1965
Flynn Creek, OR	*Oncorhynchus kisutch*	0.3- 4.9	Chapman 1965
Needle Branch, OR	*Oncorhynchus kisutch*	0.4- 5.7	Chapman 1965
Lawrence Creek, WI	*S. fontinalis*	1.3- 26.2	McFadden 1961
Valley Creek, MI	*S. fontinalis*	4.0- 26.0*	Elwood and Waters 1969

Table VI-18. Continued.

Localities	Species Composition	g/m^2	Sources
Valley Creek, MI	*S. fontinalis*	7.5- 14.8*	Hanson and Waters 1974
Spring Creek, PA	*S. trutta*, *S. gairdneri*, *S. inus fontinalis*, *Catostomus commersoni*, *Rhinichthys atratulus*, *R. cateractae*, *Semotilus corporalis*, *S. atromaculatus*, *Exoglossum maxillingua*	39.6	McFadden and Cooper 1962
Kettle Creek, PA	*S. trutta*, *S. fontinalis*, *C. commersoni*, *R. atratulus*, *R. cataractae*, *E. maxillingua*, *Campostoma anomalum*, *S. corporalis*, *S. atromaculatus*, *Notropis cornutus*, *Notemigonis chrysoleucus*, *Hybopsis micropogon*, *Noturus insignis*, *Etheostoma nigrum*	25.5	McFadden and Cooper 1962
Spruce Creek, PA	*S. trutta*, *C. commersoni*	23.7	McFadden and Cooper 1962
Young Woman's Creek, PA	*S. trutta*, *S. fontinalis*, *C. commersoni*, *R. atratulus*	15.0	McFadden and Cooper 1962
Cedar Run, PA	*S. trutta*	7.6	McFadden and Cooper 1962
Shaver Creek, PA	*S. trutta*, *S. fontinalis*, *C. commersoni*, *R. atratulus*, *R. cataractae*, *E. maxillingua*, *C. anomalum*, *S. corporalis*, *S. atromaculatus*, *H. micropogon*	5.2	McFadden and Cooper 1962
Jordan Creek, IL	*Ericymba buccata*, *Pimphales notatus*, *C. anomalum*	0.5- 3.5	Larimore 1955

Table VI-18. Concluded.

Localities	Species Composition	g/m^2	Sources
Pine River, Little Manistee River, Bordman River, MG	*S. trutta*, *S. gairdneri*, *S. fontinalis*	0.5- 20.0	Shetter and Hazzard 1939
River Yarty, U.K.	*S. trutta*, *S. salar*, unknown Salmonid	7.2-12.7	Horton et al. 1968
Walla Brook, U.K.	*S. trutta*	0.5- 2.0	Horton 1961; Horton et al 1968
River Thames, U.K.	*Rutilus rutilus*, *Perca fluviatilis*, *Alburnus alburnus*, *Leuciscus lueciscus*	47.6	Williams 1964
Shelligan Burn, Scotland	*S. trutta*, *S. salar*	0.7- 19.3	Egglishaw 1970
Horokiwi Stream, New Zealand	*S. gairdneri*	22.5*	Allen 1951

benthos and drift. When absolute densities and average individual body sizes of mayfly nymphs decreased dramatically, three fish species each shifted to a different alternate prey, and three others did not obviously respond. (One species, *G. robusta*, was not studied quantitatively.) Fishes which responded to alternate prey increased special feeding behavior and spatial partitioning of habitats. Those which did not respond remained as generalized feeders. Interspecific interactions related to feeding habits are probably minimal in Aravaipa Creek because of the abundance of food organisms and spatial segregation of the fishes.

6. Movements and Movement Patterns

Fishes were more abundant and more biomass was present within the central gorge of Aravaipa Creek in summer than outside, and *vice versa* in winter (Section VI - 4). Thus movements were indicated. Siebert (1980; see Appendix F) tagged about 2,100 roundtail chubs, desert mountain-suckers, and Sonora suckers, and determined their movements to radiate seasonally from and toward the central gorge. Dispersal was from the canyon in winter and toward it in summer, the latter presumably in response to high water temperatures. Floods had little influence on movement patterns, and home ranges or territories were not evident for most individuals studied.

7. Reproductive Notes

Specific data have not been published on reproduction and reproductive behavior of most Aravaipa Creek fishes. Barber *et al*. (1970) dealt with spikedace and Minckley and Barber (1971) discussed reproduction by longfin dace.

a. Periodicity. Evidence for reproduction includes presence of breeding coloration or other secondary sexual features such as nuptial tubercles (especially in males), maturation of gonads, observations of spawning activities, and finally, the presence of eggs and larvae. Data on such occurrences in Aravaipa Creek were gleaned from personal field notes and those of W. E. Barber and D. C. Williams, plus observations of numerous personnel in 1976-79 (Table VI-19). Most species assume breeding colors in autumn and early winter, coincident with beginning of maturation of gonads. Coloration and tuberculation of males persists throughout winter, and is intensified with onset of spawning activities in spring and early summer. Females of most species appear to develop ova to the yolked stage in autumn, then hold final maturation until a few weeks prior to the spawning act. Young fish appear in winter (speckled dace, mountain-sucker) or spring-early summer (all other species). Longfin dace spawns throughout the year, but most successfully in spring and early summer and again in summer after cessation of summer rains.

b. Habitat Selection. Fishes in Aravaipa Creek select relatively stable portions of the stream for reproduction. Shifting sand and other moving substrates are obviously unsuitable for deposition of ova. Most species spawn in moving water (Table VI-20), with even the two species that tend to deposit eggs in pool habitat (roundtail chub and longfin dace) seeking areas where slow currents are present. Four species, longfin and speckled dace, Sonora sucker, and desert mountain-sucker, place their ova within the substrate. Loach minnow attaches its adhesive eggs to the underside of cobble in a defined nest. Spikedace and roundtail chub scatter their eggs over clear gravel bottoms.

Table VI-19. Patterns of reproductive development and activity in fishes of Aravaipa Creek, Graham and Pinal counties, Arizona, based on field observations, 1966-79. Symbols: rectangles enclose principle reproductive periods based on the various criteria, with hatched areas indicating most intensive periods of spawning; "X" denotes one or more records of the feature or activity in a species, but no evidence of extensive reproduction or reproductive activity; and "-" indicates no evidence of reproduction.

Taxa	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
	Breeding Coloration and Tuberculation											
Agosia chrysogaster	X	X	X	X	X	X	X	X	X	X	X	X
Gila robusta	X	X	X	X	X	X	-	-	-	-	-	X
Meda fulgida	X	X	X	X	X	X	X	X	-	-	-	X
Rhinichthys osculus	X	X	X	X	X	X	X	X	-	-	-	X
Tiaroga cobitis	X	X	X	X	X	X	-	-	-	-	-	X
Pantosteus clarki	X	X	X	X	X	X	-	-	X	X	X	X
Catostomus insignis	X	X	X	X	X	X	X	-	-	X	X	X
	Mature Gonads											
Agosia chrysogaster	X	X	X	X	X	X	X	X	X	X	X	X
Gila robusta	X	X	X	X	X	X	-	-	-	-	-	X
Meda fulgida	X	X	X	X	X	X	X	X	X	-	-	X
Rhinichthys osculus	X	X	X	X	X	-	-	-	-	-	X	X

Table VI-19. Continued.

Taxa	J	F	M	A	M	J	J	A	S	O	N	D
Tiaroga cobitis	X	X	X	X	X	X	-	-	-	-	-	-
Pantosteus clarki	X	X	X	X	X	X	-	-	-	-	X	X
Catostomus insignis	X	X	X	X	X	X	X	-	-	X	X	X
Observations of Spawning Activities												
Agosia chrysogaster	X	X	X	X	X	X	X	X	X	X	X	X
Gila robusta	-	-	X	X	X	-	-	-	-	-	-	-
Meda fulgida	-	-	X	X	X	X	X	-	-	-	-	-
Rhinichthys osculus	X	X	X	X	-	-	-	-	-	-	-	-
Tiaroga cobitis	-	-	-	X	X	X	-	-	-	-	-	X
Pantosteus clarki	X	X	X	X	X	-	-	-	-	-	-	-
Catostomus insignis	-	-	X	X	X	X	-	-	-	-	-	-
Presence of Eggs or Young												
Agosia chrysogaster	-	-	X	X	X	X	X	X	X	X	X	-
Gila robusta	-	-	-	X	X	X	-	-	-	-	-	-
Meda fulgida	-	-	-	X	X	X	X	-	-	-	-	-

Table VI-19. Concluded.

Taxa	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Rhinichthys osculus	X	X	X	X	-	-	-	-	-	-	-	-
Tiaroga cobitis	-	-	-	X	X	X	-	-	-	-	-	-
Pantosteus clarki	X	X	X	X	X	X	-	-	-	-	-	-
Catostomus insignis	-	X	X	X	X	X	X	X	X	-	-	X

Table VI-20. Habitats used by fishes of Aravaipa Creek, Graham and Pinal counties, Arizona, for deposition of eggs.

Taxa	Reaches				Depths				Substrates					Cover			
	Rapids	Riffles	Runs	Pools	< 5 cm	> 5 < 25	> 26 < 50	> 50	Silt	Sand	Gravel	Cobble	Boulder	Barren	Algae	Higher Plants	Debris
Agosia chrysogaster			X	X	X	X			X	X				X			
Gila robusta			X	X			X	X	X	X	X			X			X
Meda fulgida			X	X	X	X			X	X	X			X			
Rhinichthys osculus	X	X			X	X					X	X	X	X	X		
Tiaroga cobitis	X	X			X	X						X	X	X	X	X	
Pantosteus clarki	X	X	X		X	X	X				X	X	X	X	X		
Catostomus insignis	X	X	X		X	X	X				X	X	X	X	X		

c. Spawning Behavior. Most fishes in Aravaipa Creek display a generalized cyprinoid spawning behavior. Males aggregate in suitable areas and females move to them when ready to spawn. A female is joined by two or more males, which flank her and emit sperm as ova are released. Release of gametes is generally associated with a flurry of activity on the part of the spawners, and this may serve to bury eggs within the substrate (suckers, speckled and longfin dace). Males of roundtail chub aggregate and move about over the substrate, tending to clear it of algae and debris. This presumably enhances placement of eggs. The spawning act of loach minnow has not been recorded.

E. Introduced Fishes

Unlike most natural waters of Arizona, Aravaipa Creek has yet to suffer from massive introductions of non-native fishes. Four species, yellow bullhead (Ictalurus natalis [Lesueur]), green sunfish (Lepomis cyanellus [Rafinesque]), largemouth bass (Micropterus salmoides [Lacepede]), and mosquitofish (Gasbusia affinis Baird and Girard), have been recorded in the watershed. Only the two centrarchids, Lepomis and Micropterus, have been taken from the mainstream. The catfish was recorded in an adjacent pond by Barber and Minckley (1966), along with largemouth bass. Mosquitofish are used at Wood's Ranch for mosquito control in stock-watering tanks, and were presumably obtained from local public health agencies. Only the green sunfish builds populations in the stream, generally at the lower end, upstream to the vicinity of Virgus Canyon, and sometimes in pools in the mouths of tributary streams. Flooding has consistently destroyed these populations.

One native species, the Sonoran topminnow (Poeciliopsis occidentalis Baird and Girard) has been repeatedly introduced into Aravaipa Creek by Arizona Game and Fish Department in an attempt to reestablish that species within its native range. These stockings have been unsuccessful over the long term, with severe flooding immediately following each attempt.

Flooding in Aravaipa Creek may preclude establishment of species introduced to date, but stream adapted species such as the red shiner (Notropis lutrensis [Baird and Girard]) almost certainly would establish and maintain populations if brought into the area. Unfortunately, stocks of game fishes are often contaminated by other fishes, including red shiner. Personnel stocking fishes seldom are attentive to such problems; any introductions are, therefore, a threat. Stock tanks in the watershed present a major concern in this regard. Many are on private lands, and thus can be monitored and controlled only through cooperative agreements. If possible, introduced fishes of all kinds should be excluded from the watershed.

Mosquitofish present a special problem. The species has been implicated in declines of numerous western fishes (Minckley 1973), and their establishment in the mainstream or tributaries of Aravaipa Creek is to be avoided. Public Health agencies in Arizona now introduce this species as a matter of course for mosquito control and should be contacted with respect to the Aravaipa Creek watershed.

VII. SUMMARY

Aravaipa Creek, central Arizona, flows through a region of rugged, Basin and Range topography. Its central gorge and lower valley partially represent an ancient, antecedent channel. Its upper valley is dissecting a northwest extension of the Sulpher Springs Valley, a structural trough formed during mountain building processes.

Climate of the area is arid and mild, with strongly bi-seasonal precipitation in winter and mid-summer. Upper Aravaipa Creek flows through desert-grassland (Upper Sonoran Life-zone), where grasses are co-mingled with shrubs and scattered trees such as juniper. Downstream, desert-grassland grades into desertscrub of the Lower Sonoran Life-zone. Vegetation along the immediate stream is a warm-temperate, winter-deciduous woodland, characterized by a gallery forest of cottonwood, willow, sycamore, and other tall trees. Drier floodplains are dominated by winter-deciduous microphylls, such as mesquite.

The stream seems similar today to photographs and published descriptions of 80-120 years ago. The upper part of the creek, near Klondyke, formerly was marshy and permanent where now incised and typically dry except in times of flood. Riparian forests were more massive in size and development in the past, but where made up of the same species of trees; young trees were abundant. Only one plant species evident in old photographs, the common reed, is now absent from the riparian community.

Historical uses of the stream and its environs included intensive livestock ranching from the late 1700s through the 1960s. Mining operations commenced in the 1860s, and smelting and concentrating of lead, zinc, and silver ores were begun in the 1970s. These activities continued until the

1950s, when operations became limited to removal of sand, gravel, and rock, and local exploratory mining.

Gradients of the channel of Aravaipa Creek vary from < 2.5 m/km near the source, to > 25 m/km within the gorge, and to < 5 m/km near its confluence with the San Pedro River. Southwest-flowing tributaries are discordant to the mainstream and include series of falls along their courses. North-flowing tributaries are larger, receive more precipitation, and have high, but uniform, gradients that enter Aravaipa Creek in an accordant fashion.

Within the gorge the stream is narrower than elsewhere, deeper on the average and at a maximum, and has less surface area and volume per unit length. It typically flows in a single channel, with a large percentage of rapids, and is heavily shaded. Outside the canyon the channel is wider and shallower but has more surface area and volume per unit length. Pools are shallower, but more common, and rapids are scarce. Percentage shading is greatly reduced, and the stream occupies an often-braided channel.

The stream flows over unconsolidated, poorly-sorted sand, gravel, cobble, and boulder. Floods originating in the upper, alluviated valley carry large volumes of silt and sand, whereas those from montane tributaries transport larger materials such as gravel and boulders. Types and origins of flooding thus have vastly different effects on the system. Alternating "sanding in" of pools is followed by degradation, to re-create a pool-riffle-pool habitat sequence.

Average stream flow in Aravaipa Creek is 2,530 hm^3/year, 61.3% of which occurs in winter and 3.87% in summer. Most winter outflow is in February-March, and August yields most water in summer. Summer base flows are bimodal, 0.14 m^3/s, and 0.28 m^3/s. The first presumably reflects base flow of the

aquifer less irrigation demands, and the second is actual base flow. Winter discharges tend to be uni-modal, a bit higher than the higher mode of summer. This results from greater winter precipitation, lower rates of evapotranspiration, and reduced irrigation.

Water passage into and out of the unconsolidated sediments of the creek bed produces marked up- to downstream variation in surface discharges. Only in places where bedrock is near the surface can reliable estimates of discharge be made as a matter of course.

Relationships of precipitation on the watershed and stream discharge were poorly correlated in winter, but highly so in summer. The average water yield of the stream is about 5.5% of available precipitation.

Annual means of water temperature in Aravaipa Creek tended to be higher than mean air temperatures in autumn, winter, and spring and lower than mean air temperature in summer. Maximum diel temperature variation was 12.6^{0} C in summer and 11.5^{0} in winter. Rates of heating ranged to > $2.0^{0} \times 10^{-2}$ in summer, beginning abruptly as light impinged upon the water surface at sunrise. Heavily shaded segments of the stream were significantly cooler than unshaded reaches.

Turbidities were low in Aravaipa Creek in all but periods during and immediately following floods. Suspended sediment loads of flood waters were high and variable and differed in composition depending upon origin of water. Flooding from the upper valley contained high percentages of colloids, and those from uplands did not.

Shading of the water surface is a significant factor in Aravaipa Creek. North-facing cliffs reduced light to < 5.0% of that present at midday in summer. Riparian trees reduced light at the water surface by 50 to 80%.

Penetration of light was 90% to the stream bottom except during flood. Angle of incidence in late evening and early morning reduced this only to 40-60%, partially as a function of refraction produced by surface turbulence.

Dissolved concentrations of major cations and order of their abundance in Aravaipa Creek were rather typical of Sonoran Desert streams, $Ca^{++} > Na^{+} > Mg^{++} > K^{+}$. Major anions were as follows: $HCO_3^{--} > CO_3^{--} > SO_4^{--} > Cl^{-}$. Except for Horse Camp Canyon where Mg^{++} exceeded Na^{+}, chemistry of all tributaries resembled that of the mainstream.

Microchemical studies of dissolved heavy metals indicated that with the exception of Hg^{++}, no element studied in the mainstream of Aravaipa Creek exceeded national or international water standards. Cd^{++} approached the maximum recommended concentration for "sensitive" species of freshwater organisms. Dissolved metals in tributaries for the most part also met recommendations for water standards: Cr^{+++}, Cu^{++}, Cd^{++}, and Pb^{++} were generally low and relatively stable in time and space. Mn^{++}, Fe^{++}, and Zn^{++}, however, were highly variable. Turkey Creek had Mn^{++} that regularly exceeded standards for domestic water supplies. The single sample from Bear Canyon had Fe^{++} that exceeded all standards, and water in Horse Camp Canyon exceeded the standard for aquatic life in August. An unnamed tributary exceeded recommended standards for Hg^{++} in domestic water supplies, and all tributaries had more Hg^{++} than is recommended for aquatic organisms and wildlife uses.

Mean concentrations of total metals in Aravaipa Creek were in all instances substantially higher than dissolved levels (to 50 fold). Highest particle-bound loads were associated with turbidity during floods. Tributaries, with some exceptions, were less extreme in total metals than the mainstream. This may, however, be an artifact of more comprehensive sampling

of the channel. The major exception was Hell Hole Canyon, where total concentrations for Cr^{+++}, Cu^{++}, Cd^{++}, Fe^{++}, Mn^{++}, Pb^{++}, and Zn^{++}, were from 20 to more than 10,000 times dissolved levels during high discharge and turbidity. High particle-bound amounts of heavy metals may be attributable to mine seepage and exposed mine wastes in the watershed.

Dissolved oxygen concentration in Aravaipa Creek varied inversely to seasonal water temperatures, and in periods of high productivity varied positively with daytime light. In periods of low productivity, nighttime oxygen concentrations exceeded those in daylight hours. During periods of high productivity, oxygen was supersaturated in daytime, despite turbulence of the stream. Community respiration at night likewise lowered oxygen levels to substantially below saturation on occasion, although never to a level critical to the biota. Low dissolved oxygen was associated with flash flooding and periods of biomass deterioration; reasons for the first relationship are obscure and merit further study.

Specific conductance in Aravaipa Creek ranged between 158 and 510 umhos/cm, with means for 24-hour studies generally falling between 430 and 480 umhos/cm. Grand means for paired sampling periods up- and downstream from the gorge were 447.8 and 434.9 umhos/cm, respectively, with the lower value downstream reflecting precipitation of certain ions, input of local rainfall, or inflows from more dilute tributary canyons.

The lowermost reach of Aravaipa Creek was invariably higher in pH than the upper reach, and values were lower in summertime and at night than in winter and during daylight hours.

Of the macronutrients, PO_4-P was relatively constant in concentration up- to downstream, before and after floods, and throughout the year. NO_3-N, on

the other hand, was always lower downstream than in upper reaches, higher after periods of high flow, and lower after periods of low flow when productivity was high in both the upper and lower reaches. The system would be NO_3-N-limited if nacronutrients were in short supply.

Forty-eight algal genera were identified from Aravaipa Creek. The community is dominated by diatoms and the green alga Cladophora glomerata. Standing crops of periphyton was significantly higher in relatively unshaded reaches above and below Aravaipa Canyon than those within the shaded gorge. Flooding essentially removed algae from the system. The encrusting community recovered quickly after floods, increasing its biomass by 18 to 43 times within the first 30 days, and attaining or exceeding pre-flood conditions between 16 and 45 days after a spate. Cladophora was slower in recovery, increasing biomass 8.5 to 20 times in 30 days, and becoming most luxurient 45 to 90 days after a flooding event. Standing crops of algae in unshaded parts of the stream exceeded reported values for temperate streams.

Detrital materials were most abundant in Aravaipa Creek after flooding, becoming comparable in standing crops to those of periphyton after periods of low discharge. Downstream export reduced standing crops of detritus by about 70% in 16 to 45 days after a flood.

Benthic invertebrates are rich and diversified in the Aravaipa Creek system, and a total of 133 taxa (109 insects) were recorded. Greatest numbers of individuals and taxa and greatest biomass were present in late winter and spring, followed by a consistent decline during summer rains and flooding. Numbers and biomass recovered quickly, generally achieving pre-flood conditions by 45 to 90 days after disruption. Recovery time depended upon frequency of previous flooding. After a single spate, density and biomass

could achieve pre-flood levels within 15 days, but repeated floods resulted in longer periods required for recovery.

Of organisms collected in drift samples, only baetid and trycorythid mayflies and chironomid dipteran larvae and pupae were present in all samples on all sampling dates. Numbers of those animals in drift and in the benthos correlated roughly, but no relationship existed between weights in drift and those in the benthic community.

All seven native fishes now occupying Aravaipa Creek were formerly more widespread and abundant in the Gila River system than they are today. All have suffered reductions in range, especially at lower elevations, as a result of water developments, desiccation, and interactions with introduced forms. Patterns of abundance of fishes within the stream have been remarkably consistent since the 1940's. When direct comparisons are available, longfin dace almost always are most abundant downstream, below the gorge, and least abundant within the gorge. Speckled dace averaged twice as abundant above the gorge as within it and rarely occur downstream. Loach minnow tend to be most common above the gorge. Sonora sucker, desert mountain-sucker, roundtail chub, and spike dace all tended to be most abundant within the gorge, second upstream, and least abundant downstream.

Biomass of total fishes in Aravaipa Creek is spectacularly high at some times of year, and varies significantly in different segments of the stream. Total weights/unit area were greater above and below the gorge than within it in spring, autumn, and winter, but were far greater within the gorge in summer. Biomass and numbers of fishes in Aravaipa Creek are substantially higher than those reported from temperate and high-altitude streams, but compare favorably with other low-desert systems.

Fishes in Aravaipa Creek exhibit three trophic patterns: herbivory by the mountain-sucker; omnivory by longfin dace; and carnivory by the remaining five species. Ephemeropteran nymphs were the major food of all carnivorous fishes and of the omnivore, and were the dominant invertebrate in both benthos and drift. Interspecific interactions related to feeding habits of fishes are probably minimal in Aravaipa Creek because of the abundance of invertebrates and spatial segregation of the fishes themselves.

Dispersal of tagged fishes was from the central gorge in winter and toward it in summer. Movement into the shaded reach presumably reflected an avoidance of high water temperatures in more open portions of the stream. Flooding had little influence on movement patterns.

Most fishes in Aravaipa Creek assume breeding colors in autumn and early winter, then spawn in spring and early summer. All select relatively stable portions of the stream for reproduction. Most species display a generalized cyprinoid spawning behavior, males aggregating in suitable areas and females moving to them when prepared to spawn.

No alien fish species introduced into Aravaipa Creek has yet established a reproducing population for more than a year or two. Flooding appears to be too severe for species such as green sunfish and largemouth bass. However, stream-adapted species now occur in the vicinity, and their introduction into the system is to be avoided.

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Appendix A

CATALOGUE OF VASCULAR PLANTS OCCURRING IN THE ARAVAIPA CREEK PRIMITIVE AREA

Several collecting trips were made through the Aravaipa Canyon Primitive Area during the course of a year. In order to identify the flora of Aravaipa Creek from the confluence of Turkey Creek to Woods Ranch and adjacent hillsides, with the listing expanded to include specimens from above and below these boundaries. Plant species were recorded according to personal observation and those specimens collected and processed were deposited at the Desert Botanical Garden herbarium (DES) Phoenix, Arizona. Identifications were made according to Kearney et al. (1960), except for Cactaceae which followed Benson (1969). Certain other groups are treated according to recent revisions and monographic treatments (Lehr 1978).

The vascular flora listed for the Aravaipa Creek Primitive Area consists of 150 species in 128 genera representing 58 families. Each species is grouped by family and followed by its author and common name, if available. The sequence of families follows that of Kearney and Peebles in Arizona Flora and the genera within each family are arranged by alphabetical order. All species listed have been reviewed for recent taxonomic revisions according to Lehr (1978) and their most current synonomy has been included. Plant specimens that were not in flower could not be keyed to species and are therefore listed in the catalogue at the generic level only. They were included in an effort to make the catalogue as complete as possible, fully realizing that it at best represents a partial list of the actual flora for the Aravaipa area.

DIVISION: PTERIDOPHYTA. Ferns and Fern Allies

POLYPODIACEAE. Fern Family

Adiantum capillus-veneris L. Southern maidenhair fern

Asplenium resiliens Kunze. Small spleenwort

Cyrtomium auriculatum (Underw.) Morton.

Thelypteris puberula (Baker) Morton var. *sonorensis* A. Reid Smith.

DIVISION: SPERMATOPHYTA. Flowering Plants

CLASS: GYMNOSPERMAE

CUPRESSACEAE. Cypress Family

Juniperus monosperma (Engelm.) Sarg. One-seed juniper

CLASS: ANGIOSPERMAE

SUBCLASS: MONOCOTYLEDONEAE

TYPHACEAE. Cat-tail Family

Typha sp. Cattail

GRAMINEAE. Grass Family

Bromus rubens L. Red brome

Cynodon dactylon (L.) Pers. Bermuda grass

Schismus barbatus (L.) Thell. Mediterranean grass

LEMNACEAE. Duckweed Family

Lemna sp. Duckweed

AGAVACEAE. Agave Family

Agave chrysantha Peebles. Century plant

Dasylirion wheeleri Wats. Desert spoon, sotol

Nolina microcarpa Wats. Beargrass

SUBCLASS: DICOTYLEDONEAE

SALICACEAE. Willow Family

Populus fremonti Wats. Fremont cottonwood

Salix bonplandiana H.B.K. Bonpland willow

Salix gooddingii Ball. Goodding willow

JUGLANDACEAE. Walnut Family

Juglans major (Torr.) Heller. Arizona walnut

FAGACEAE. Beech Family

Quercus turbinella Greene. Scrub oak

Quercus sp.

ULMACEAE. Elm Family

Celtis pallida Torr. Desert hackberry

Celtis reticulata Torr. Net-leaf hackberry

MORACEAE. Mulberry Family

Morus microphylla Buckl. Texas mulberry

VISCACEAE. Mistletoe Family

Phoradendron californicum Nutt. Desert mistletoe

Phoradendron tomentosum (DC.) Gray (*P. flavescens* (Pursh) Nutt.). Inierto

POLYGONACEAE. Buckwheat Family

Eriogonum abertianum Torr.

Polygonum lapathifolium L. Willow smartweed

Polygonum sawatchense Small.

Rumex sp. Dock

CHENOPODIACEAE. Goose Foot Family

Atriplex canescens (Pursh) Nutt. Four-wing saltbush

Salsola iberica Sennen and Pau (S. kali L. var. *tenuifolia* (Tausch) Aellen). Russian thistle, tumbleweed

AMARANTHACEAE. Amaranth Family

Amaranthus fimbriatus (Torr.) Benth. Fringed amaranth

NYCTAGINACEAE. Four O'Clock Family

Allionia incarnata L. Trailing four o'clock

PHYTOLACCACEAE. Pokeberry Family

Rivina humilis L. Rouge plant, coralito

BERBERIDACEAE. Barberry Family

Berberis trifoliata Moric. Algerita

CRUCIFERAE. Mustard Family

Lesquerella gordoni (Gray) Wats. Gordon bladderpod

Lesquerella purpurea (Gray) Wats.

Nastuntium officinale L. Water-cress

Sisymbrium irio L. London skyrocket

PLANTANACEAE. Plane Tree Family

Plantanus wrightii Wats. Arizona sycamore

CROSSOSOMATACEAE. Crossosoma Family

Crossoma bigelovii Wats. Bigelow ragged rock flower

ROSACEAE. Rose Family

Prunus sp.

LEGUMINOSAE. Pea Family

MIMOSOIDEAE. Mimosa Subfamily

Acacia constricta Benth. White-thorn acacia

Acacia greggii Gray var. *arizonica* Isley (*A. greggii* Gray). Catclaw

Calliandra eriophylla Benth. Fairy duster

Desmanthus sp. Bundleflower

Mimosa biuncifera (Benth.) Britt. and Rose. Wait-a-minute bush

Prosopis velutina Woot. (*P. juliflora* (Swartz) DC. var. *velutina* (Woot.) Sarg.). Velvet mesquite

CAESALPINIOIDEAE. Senna Subfamily

Cassia covesii Gray. Desert senna

Cercidium floridum Benth. Blue paloverde

Cercidium microphyllum (Torr.) Rose and Johnst. Yellow or little-leaf paloverde

PAPILIONOIDEAE. Bean Subfamily

Amorpha fruticosa L. var. *occidentalis* (Abrams) Kearn. and Peeb. Bastard indigo

Astragalus sp. Loco weed

Lotus rigidus (Benth.) Greene. Desert rock pea, deer vetch

Lupinus sp. Lupine

Medicago sativa L. Alfalfa

Trifolium sp. Clover

GERANIACEAE. Geranium Family

Erodium cicutarium (L.) L'Hér. Heron-bill

OXALIDACEAE. Wood Sorrel Family

Oxalis sp.

ZYGOPHYLLACEAE. Caltrop Family

Larrea divaricata Cav. Creosote bush

RUTACEAE. Rue Family

Choisya arizonica Standl. Star-leaf

Ptelea trifoliata L. subsp. *angustifolia* (Benth.) V. L. Bailey (*P. angustifolia* Benth.). Narrowleaf hoptree

MALPIGHIACEAE. Malpighia Family

Janusia gracilis Gray.

EUPHORBIACEAE. Spurge Family

Acalypha ostryaefolia Riddell. Hornbeam three-sided mercury

Croton texensis (Klotzsch) Muell. Arg. Dove-weed

Euphorbia sp. Spurge

SIMMONDSIACEAE. Jojoba Family

Simmondsia chinensis (Link) Schneid. Jojoba (usually included in the Family Buxaceae)

ANACARDIACEAE. Cashew Family

Rhus radicans L. var. *rydbergii* (Small) Rehder. Poison Ivy

Rhus trilobata Nutt. Skunk-bush, squaw-bush

ACERACEAE. Maple Family

Acer negundo L. var. *interius* (Britt.) Sarg. Box elder

SAPINDACEAE. Soapberry Family

Sapindus saponaria L. var. *drummondii* (Hook. and Arn.) Benson. Western soapberry

MELIACEAE. Melia Family

Melia azedarach L. China-berry tree

RHAMNACEAE. Buckthorn Family

Rhamnus californica Esch. subsp. *ursina* (Greene) Wolf. California buckthorn

Rhamnus crocea Nutt. var. *ilicifolia* (Kell.) Greene. Hollyleaf buckthorn

Sagereita wrightii Wats.

Zizyphus obtusifolia (Hook. ex Torr. and Gray) Gray var. *canescens* (Gray M. C. Johnst. (*Condalia lycioides* (Gray). Graythorn

VITACEAE. Grape Family

Vitis arizonica Engelm. Canyon grape

MALVACEAE. Mallow Family

Anoda cristata (L.) Schlecht. Spurred anoda

Malva parviflora L. Cheeseweed

Saphaeralcea ambiqua Gray. Desert mallow

TAMARICACEAE. Tamarix Family

Tamarix pentandra Pall. Saltcedar

PASSIFLORACEAE. Passion Flower Family

Passiflora mexicana Juss. Passion flower

CACTACEAE. Cactus Family

Cereus giganteus Engelm. (*Carnegiea gigantea* (Engelm.) Britt. and Rose). Saguaro

Echinocereus spp. Hedgehog

Ferocactus wislizenii (Engelm.) Britt. and Rose. Fish-hook barrel

Mammillaria spp. Pincushion

Opuntia acanthocarpa Engelm. and Bigel. Buckhorn cholla

Opuntia fulgida Engelm. Chain-fruit cholla

Opuntia kleiniae DC. var. tetracantha (Toumey) W. T. Marshall (O. tetracantha) Toumey. Klein cholla

Opuntia leptocaulis DC. Christmas cactus

Opuntia phaeacantha Engelm.

var. discata (Griffiths) Benson and Walkington (O. engelmanni Salm-Dyck). Engelmann prickly pear

var. laevis (Coult.) L. Benson (O. laevis Coult.).

Opuntia stanlyi Engelm. Devil cholla

ONAGRACEAE. Evening Primrose Family

Zauschneria californica Presl subsp. latifolia (Hook.) Keck. Hummingbird trumpet

UMBELLIFERAE. Parsley Family

Bowlesia incana Ruiz and Pavon. Hairy bowlesia

PRIMULACEAE. Primrose Family

Anagallis arvensis L. Scarlet pimpernel

PLUMBAGINACEAE. Plumbago Family

Plumbago scandens L. Leadwort

FOUQUIERIACEAE. Ocotillo Family

Fouquieria splendens Engelm. Ocotillo

OLEACEAE. Olive Family

Fraxinus pennsylvanica Marsh. subsp. velutina (Torr.) G. N. Miller. Velvet ash

ASCLEPIADACEAE. Milkweed Family

Asclepias linaria Cav. Milkweed

CONVOLVULACEAE. Morning Glory Family

Cuscuta sp. Dodder

POLEMONIACEAE. Phlox Family

Phlox tenuifolia E. Nels.

VERBENACEAE. Vervain Family

Verbena sp. Vervain

LABIATAE. Mint Family

Marrubium vulgare L. Horehound

Salvia amissa Epling. Sage

Stachys coccinea Jacq. Texas betony

SOLANACEAE. Potato on Night shade Family

Datura meteloides DC. Sacred datura, jimson weed

Lycium pallidum Miers. Wolfberry

Nicotiana glauca Graham. Tree tobacco

Petunia parviflora Juss. Wild petunia

Physalis acutifolia (Miers) Sandw. (P. wrightii Gray). Wright ground cherry

Solanum douglasii Dunal. Nightshade

SCROPHULARIAECEAE. Figwort Family

Maurandya antirrhiniflora Humb. and Bonpl. Blue snapdragon vine

Mimulus dentilobus Robins. and Fern. Monkey flower

Veronica anagallis-aquatica L. Water speedwell

ACANTHACEAE. Acanthus Family

Carlowrightia arizonica Gray.

RUBIACEAE. Madder Family

Cephalanthus occidentalis L. var. californicus Benth. Button bush

Galium aparine L. Bedstraw

CURCURBITACEAE. Gourd Family

Marah gilensis Greene. Wild cucumber

CAMPANULACEAE. Bellflower Family

Lobelia cardinalis L. subsp. graminea (Lam.) McVaugh. Cardinal flower

COMPOSITAE. Sunflower Family

Acourtia wrightii (Gray) Reveal and King (*Perezia wrightii* Gray). Brownfoot

Ambrosia ambrosioides (Cav.) Payne (*Franseria ambrosioides* Cav.). Canyon ragweed

Ambrosia confertiflora DC. (*Franseria confertiflora* (DC). Rydb.). Slimleaf bursage

Ambrosia deltoidea (Torr.) Payne (*Franseria deltoidea* Torr.). Triangle-leaf bursage

Artemisia ludoviciana Nutt. Sagebrush

Aster subulatus Michx. var. *ligulatus* Shinners (A. exilis Ell.). Aster

Baccharis salicifolia (Ruiz and Pavon) Pers. (*B. glutinosa* Pers.). Seep willow

Baccharis sarothroides Gray. Desert broom

Baileya multiradiata Harv. and Gray. Desert marigold

Bebbia juncea (Benth.) Greene. Chuckawalla's delight

Bidens pilosa L. Bur marigold

Brickellia californica (Torr. and Gray) Gray. Pachaba, brickel bush

Encelia farinosa Gray. Brittle bush

Ericameria cuneata (Gray) McClatchie var. *spathulata* (Gray) Hall (*Haplopappus cuneatus* Gray var. *spathulata* (Gray) Blake). Desert rock golden bush

Erigeron divergens Torr. and Gray. Spreading fleabane

Erigeron oreophilus Greenm.

Gnaphalium sp. Cudweed

Haplopappus spinulosus (Pursh) DC.

Haplopappus tenuisectus (Greene) Blake. Burroweed

Helenium thurberi Gray. Sneeze weed

Hymenoclea monogyra Torr. and Gray. Burro bush

Hymenothrix wislizenii Gray.

Hymenothrix wrightii Gray.

Hachaeranthera sp. sensu Cronquist and Keck

Perityle lemmoni (Gray) Macbride (Laphamia lemmoni Gray and L. dissecta Torr. sensu Kearn. and Peeb.).

Porophyllum gracile Benth. Odora

Psilostrophe cooperi (Gray) Greene. Paperflower

Solidago wrightii Gray. Goldenrod

Stephanomeria pauciflora (Torr.) A. Nels. Desert straw

Viguiera multiflora (Nutt.) Blake. Golden eye

Xanthium strumarium L. (X. saccharatum Wallr.). Cocklebur

SUMMARY BY MAJOR TAXA OF THE
KNOWN VASCULAR FLORA OF ARAVAIPA CREEK PRIMITIVE AREA

Major Taxa	Families	Genera	Species
Pteridophyta	1	4	4
Spermatophyta			
Gymnospermae	1	1	1
Angiospermae			
Monocotyledonae	4	8	8
Dicotyledonae	52	115	137
Totals	58	128	150

LIST OF AUTHOR NAME ABBREVIATIONS

Benth.	G. Bentham
Bigel.	J. Bigelow
Britt.	N. L. Britton
Britt. and Rose	N. L. Britton and J. N. Rose
Buckl.	S. B. Buckley
Cav.	A. J. Cavanilles
Coult.	J. M. Coulter
DC.	A. P. de Candolle
Ell.	S. Elliot
Engelm.	G. Engelmann
Esch.	J. R. Eschscholtz
Fern.	M. L. Fernald
Greenm.	J. M. Greenman
H.B.K.	F. W. H. von Humboldt
Harv.	W. H. Harvey
Hook.	W. J. Hooker
Hook. and Arn.	W. J. Hooker and G. A. W. Arnott
Humb. and Bonpl.	F. W. H. von humboldt and A. J. A. Bonpland
Jacq.	N. J. von Jacquin
Johnst.	I. M. Johnston
M. C. Johnst.	M. C. Johnston
Juss.	A. L. de Jussieu
Kearn. and Peeb.	T. H. Kearney and R. H. Peebles
Kell.	A. Kellogg
L.	C. Linnaeus
Lam.	J. B. de Lamarck
L'Hér.	C. L. L'Héritier de Brutelle

Marsh.	H. Marshall
Michx.	A. Michaux
Moric.	M. E. Moricand
Muell. Arg.	J. Mueller
A. Nels.	A. Nelson
E. Nels.	E. E. Nelson
Nutt.	T. Nuttal
Pall.	P. S. Pallas
Pers.	C. H. Persoon
Robins.	B. L. Robinson
Ruiz and Pavon	H. R. Lopez and J. A. Pavon
Rydb.	P. A. Rydberg
Sandw.	N. Y. Sandwith
Sarg.	C. S. Sargent
Schlecht.	D. F. L. von Schlechtendal
Schneid.	C. K. Schneider
Standl.	P. C. Standley
Thell.	A. Thellung
Torr.	J. Torrey
Torr. and Gray	J. Torrey and A. Gray
Underw.	L. M. Underwood
Wallr.	C. F. W. Wallroth
Wats.	S. Watson
Woot.	E. O. Wooton

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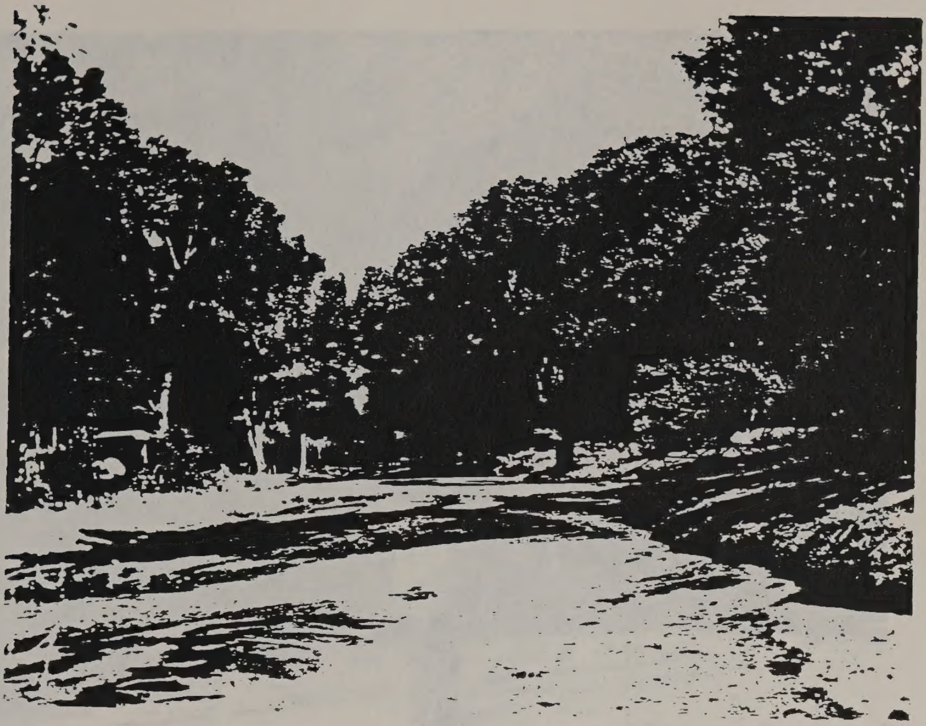
APPENDIX B

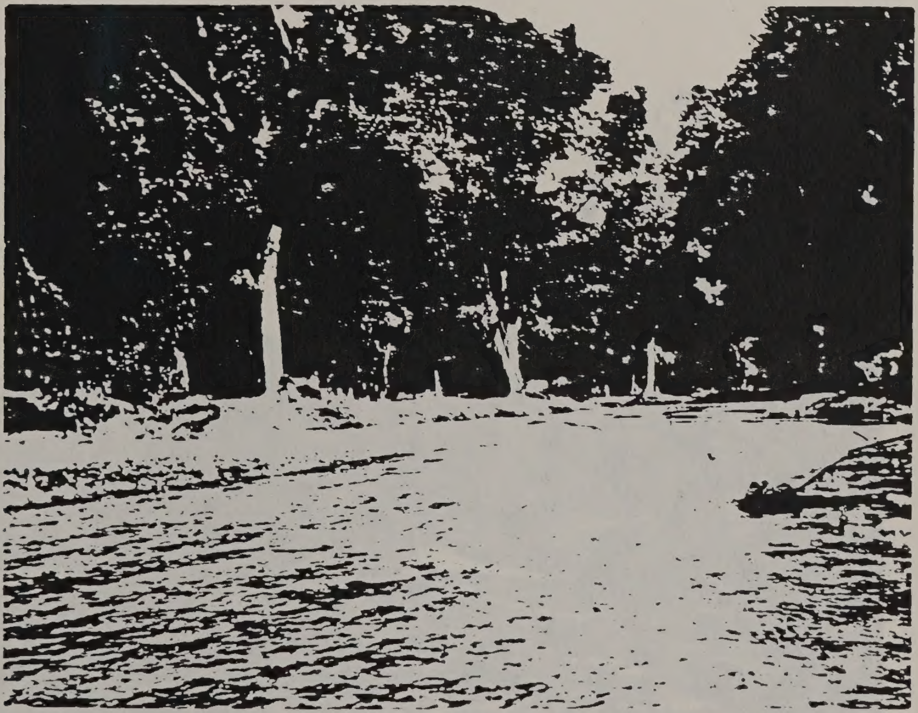
Historical Photographs of Aravaipa Creek and its environs

Photograph by Joseph Amasa Munk, 1889-1900, of Aravaipa Creek near Klondyke; courtesy of Southwest Museum, Highland Park, Los Angeles, California.

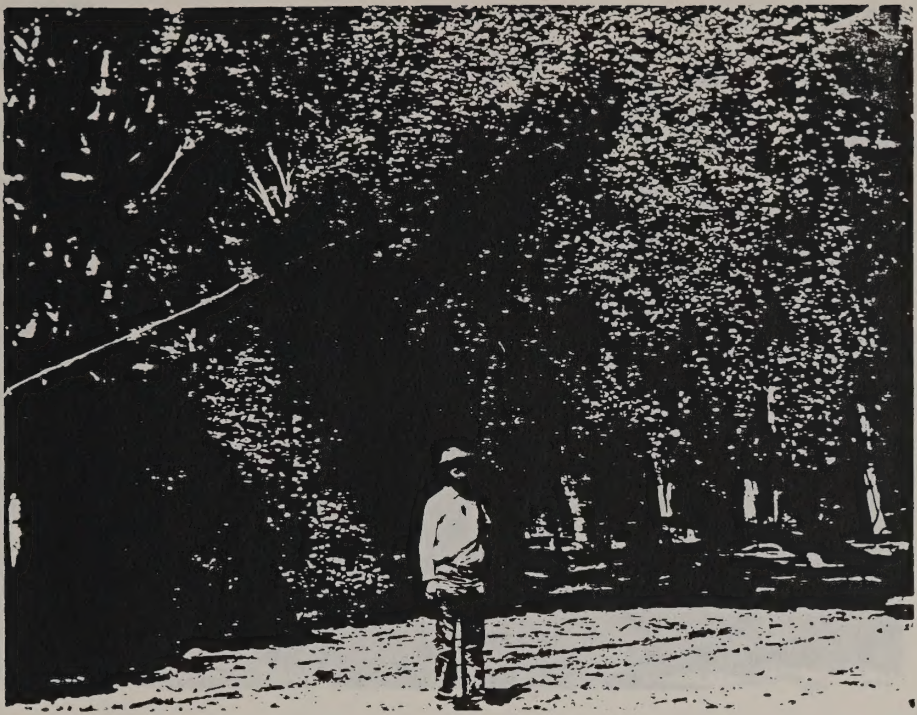
Photograph by Joseph Amasa Munk, 1889-1900, of Aravaipa Creek at the "Chimney"; courtesy of Southwest Museum, Highland Park, Los Angeles, California.



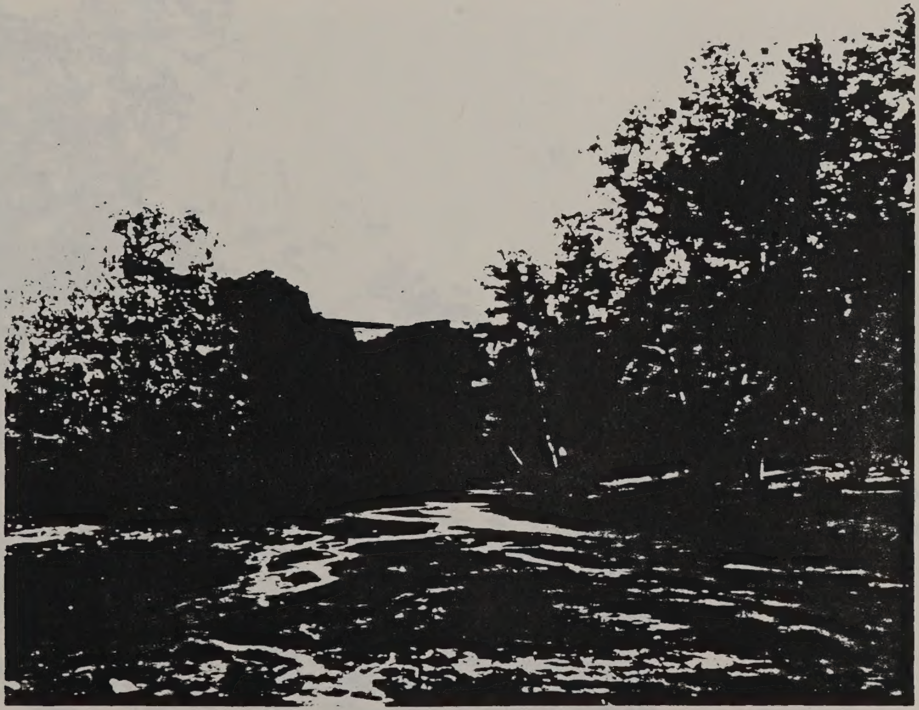
Photograph by Joseph Amasa Munk, 1889-1900, of Aravaipa Creek near its upper end; courtesy of Southwest Museum, Highland Park, Los Angeles, California.



Photograph by Joseph Amasa Munk, 1889-1900, of Aravaipa Creek at the same locality as above; courtesy of Southwest Museum, Highland Park, Los Angeles, California.



Photograph by Joseph Amasa Munk, 1889-1900, of Aravaipa Creek gallery forest, location unknown; courtesy of Southwest Museum, Highland Park, Los Angeles, California.



Unknown photographer, "before 1900," of upper Aravaipa Creek; Arizona Historical Society photograph 8208, Tucson, Arizona.

Unknown photographer, "before 1900," within Aravaipa Canyon; Arizona Historical Society photograph 8209(a), Tucson, Arizona.

Unknown photographer, "before 1900," within Aravaipa Canyon; Arizona Historical Society photograph 8209(b), Tucson, Arizona.

Unknown photographer, "donated 1939," within Aravaipa Canyon; Arizona Historical Society photograph 6903, Tucson, Arizona.

Unknown photographer, "donated 1939," within Aravaipa Canyon; Arizona Historical Society Photograph 6902, Tucson, Arizona.

Bureau of Land Management photograph, within Aravaipa Canyon, early 1970s.

Unknown photographer, undated, men fishing with wier and dip net, Aravaipa Creek, Arizona; Arizona Historical Society photograph 6901, Tucson, Arizona.

Appendix C

Mines and Mine Workings of the upper Aravaipa Creek area

The following information was compiled from the literature and includes recorded mines and prospects of the USGS Klondyke Quadrangle (Simons 1964). Some localities may in fact be outside the Aravaipa Creek drainage basin, but were included since their presence indicates exising and discovered ore bodies of the area from which heavy metals or other contaminants may originate and enter the aquatic system (Appendix Tables C-1 - C-2).

Appendix Table C-1. Mines and mine workings of the upper Aravaipa Creek area, southeastern Arizona. The abbreviation "us" indicates unsurveyed parts of the area.

Name and locations	Legal Descriptions	Product(s)	References
Arizona Mining Co. Concentrator, Klondyke	SW¼, S-6, T7S, R20E	Ore concentrate	Simons 1964
Arizona Mine	Center, W½, S-25 (us), T5S, R19E	Unknown	Ross 1925, Wilson 1950
Fairview Prospect, 4,000 ft NW Aravaipa (town)	Line between S-25-26 (us), T5S, R19E	Unknown	Simons 1964
Head Center Mine, E side Williamson Canyon	SE¼, SW¼, S-19, T5S, R20E	Lead, zinc, silver	Denton 1947b, Wilson 1950
Grand Central Mine, 1,000 ft SE Head Center Mine	Near center, N edge S-30, T5S, R20E	Lead, zinc, silver	Wilson 1950
Iron Cap Mine, ¼ mi N Landsman Camp	SE¼, S-19, T5S, R20E	Unknown	Denton 1947b, Wilson 1950
No. 1 Mine, W of Aravaipa (town) in Arizona Gulch	Unknown	Lead	Denton 1947b, Wilson 1950
Panama Mine, in gulch E of Aravaipa (town)	Unknown	Unknown	Simon 1964
Abe Reed Mine, near top SE wall of Old Deer Creek	Center, S-23 (us), T5S, R19E	Lead	Ross 1925
Ben Hur Mine, just N rd to Aravaipa (town)	SE¼, S-36 (us), T5S, R19E	Lead, zinc, silver, gold	Bromfield 1951, in Simons 1964
Cobre Grande Mine, ca. 7 mi N Cobre Grande Mtn.	Corner common to S-21, 22, 27, 28, T5S, R20E	Unknown	Ross 1925

Appendix Table C-1. Continued

Name and locations	Legal Descriptions	Product(s)	References
Copper Bar and Sam Jones Prospects, N and S sides Copper Canyon, respectively	S of center S-32, T5S, R20E	Copper, Silver, gold	Ross 1925
Last Chance Mine	SW corner S-23 (us), T5S, R19E	Lead	Simons 1964
Lead King Mine, bottom of Stowe Gulch just above Tule Canyon	near center N edge S-6, T6S, R20E	Lead	Simons 1964
Orejana Mine, 1¼ mi NW Aravaipa (town)	Center S-26 (us), T5S, R19E	Unknown	Simons 1964
Princess Pat Mine, just N Old Deer Creek	NW¼ S-13 (us), T5S, R19E	Copper	Ross 1925
Sinn Fein Mine, just SW Head Center Mine	On line between S-19-30 T5S, R20E	Lead, copper, gold, silver	Ross 1925
Tule Mine, E of Tule Spring	SE¼, S-31, T5S, R20E	Unknown	Simons 1964
Windsor Mine, NE flank Imperial Mtn, ½ way between Stowe Gulch and summit	Unknown	Unknown	Ross 1925
Unnamed	SW corner, S-8, T6S, R20E, and SW¼, NW¼, S-17, T6S, R20E	Unknown	Simons 1964
Tenstrike Mine	SW¼, S-17, T6S, R20E	Lead(?)	Ross 1925
Unnamed, probably on Alta No. 3 Claim	Center S-20, T6S, R20E and SW¼, S-20, T6S, R20E	Unknown	Simons 1964

ppendix Table C-1. Concluded.

Name and locations	Legal Descriptions	Product(s)	References
Grand Reef Mine, N side Laurel Canyon, above Waterfall Canyon	NE¼, S-29, T6S, R20E	Lead	Ross 1925, Wilson 1950
Dogwater Mine, in E branch Laurel Canyon	NW corner, S-33, T6S, R20E	Lead(?)	Ross 1925
Junction Prospect, N of Waterfall Canyon	Center W½, S-33, T6S, R20E	Unknown	Simons 1964
Laclede Mine, in branch of Klondyke Wash	N of center S-10 (us), T7S, R20E	Unknown	Ross 1925
Silver Coin Mine, south branch of Klondyke Wash	SW¼, S-11 (us), T7S, R20E	Lead(?)	Ross 1925
Table Mountain Mine, W side Virgus Canyon	SE¼, S-15 and NW¼, S-22 T7S, R18E	Gold, Copper, Lead	Simons 1964
American Eagle Mine	SW¼, S-11, T8S, R18E	Copper	Weed 1913, Denton 1947a
Childs-Aldwinkle Mine	Center W edge S-11, T8S,	Copper, Molybdenum	Kuhn 1941, 1951, Denton 1947a
Copper Giant Mine	N of S edge SE¼, S-3, T8S, R18E	Copper(?)	Weed 1913
Copper Prince Mine	NE¼, S-10, T8S, R18E	Copper	Weed 1913, Kuhn 1941, Joraleman 1952, Galbraith and Brennan 1959
Glory Hole Mine (Globe Mine)	N of center of S edge S-3, T8S, R18E	Copper	Weed 1913, Kuhn 1941
Old Reliable Mine	Center S-10, T8S, R18E	Copper	Weed 1913, Kuhn 1941, Denton 1947a, Galbraith and Brennan 1959
Bluebird Mine	SE¼, S-2, T8S, R18E	Copper	Kuhn 1951, Brennan 1959

Appendix Table C-2. Miscellaneous exploratory prospects of the upper Aravaipa Creek Area, southeastern Arizona (from Simons 1964).

Names and locations (if known)	Legal Description
Unnamed, S of Old Deer Creek	Center S-18, T5S, R20E
Green Gem Claim	Center of line between S-17 & 20, T5S, R20E
Unnamed	SE corner S-23 (us), T5S, R19E
Silver Reef Claim	NE¼, S-25 (us), T5S, R19E
Booker T. Washington Claim	NW¼, S-30, T5S, R30E
Unnamed, 2,000 ft SE Head Center Mine	N½, S-30, T5S, R20E
Unnamed, or Ionia Claim, S of Iron Cap Mine	NE¼, S-30, T5S, R20E
Unnamed, N-NE Landsman Camp	NW¼, S-29, T5S, R20E
Unnamed, along and N road between Aravaipa (town) and Tule Spring	SE¼, S-25 (us), T5S, R19E
Unnamed	NE¼, S-36 (us), T5S, R19E
Unnamed	Near center S edge S-32, T5S, R20E
Unnamed, between Stowe Gulch and Jct. Landsman Camp and Klondyke-Aravaipa Rds.	NW¼, S-6, T6S, R20E
Unnamed, 3 prospect pits	SW¼, S-34, T6S, R20E
Unnamed, upper Klondyke Wash or Spring Canyon	SE¼, S-34, T6S, R20E
Unnamed, upper Klondyke Wash or Spring Canyon	SW¼, S-2 (us), T7S, R20E
Unnamed, upper Klondyke Wash or Spring Canyon	NE¼, S-13 (us), T7S, R20E
Unnamed, S of divide between Turkey Ck and Right Prong Four-mile Ck	NW¼, SE¼, S-28, T7S, R19E
Unnamed, S side Right Prong Four-mile Creek	S-32, T7S, R19E
Unnamed, S side Right Prong Four-mile Creek, 100 ft NW of above	S-32, T7S, R19E

Appendix Table C-2. Continued

Names and locations (if known)	Legal Description
Unnamed, N side Right Prong Fourmile Creek	NW¼, S-32, T7S, R19E
Unnamed, N side Right Prong Fourmile Creek	Center NW¼, S-33, T7S, R19E
Unnamed, on or near crest of Galiuro Mtns.	SW corner, S-32, T7S, R19E
Unnamed, on or near crest of Galiuro Mtns.	NW corner, S-5, T8S, R19E
Unnamed, on or near crest of Galiuro Mtns.	NE corner, S-6, T8S, R19E
Unnamed, 200 ft W and slightly below above locality	Unknown
Three prospects SW of crest of ridge	S-6, T8S, R19E
Copper Hill Prospect	Center S½, S-6, T8S, R19E
Unnamed	Center SE¼, S-6, T8S, R19E
Unnamed	SE corner, S-6, T8S, R19E
Unnamed, in or near fossil volcanic cone	SW¼, S-5, T8S, R19E
Unnamed, 900 ft N of above	Unknown
Unnamed, 600 ft farther NW	SW¼, S-5, T8S, R19E
Unnamed, 800 ft farther NW	SW¼, NW¼, S-5, T8S, R19E
Mission No. 1 Claim	NW¼, S-7, T8S, R19E
Mission No. 4 Claim	N½, S-7, T8S, R19E
Buena Suerte Claim (2 prospects)	NE¼, NE¼, S-7, T8S, R19E
Unnamed, 1,000 ft N-NE Glory Hole Mine	SE¼, S-3, T8S, R18E
Unnamed	NE¼, S10, T8S, R18E
Unnamed	SW corner, S-2, T8S, R18E

Appendix Table C-2. Concluded.

Names and locations (if known)	Legal Description
Unnamed, (3 prospects)	NW¼, S-11, T8S, R18E
Unnamed, where rd from Old Reliable Mine crosses Copper Ck	Center S-10, T8S, R18E
Unnamed, S side Copper Ck, ca. 900 ft SE above	Unknown
Unnamed, in deep, south-sloping canyon on W side Copper Ck	W½, S-10, T8S, R18E
Unnamed	near center N edge S-11, T8S, R18E
Unnamed, near junction of 2 west-sloping gullies	Center of line between S-11 & 12, T8S, R18E
Unnamed, near S-pointing, sharp bend in Copper Ck	NW¼, S-12, T8S, R18E
Unnamed, E side Copper Ck and 700 ft farther NW of above	Unknown
Farther NW of above, hillside N Copper Ck dotted with pits	Unknown
Unnamed	S-12, T8S, R18E
Unnamed	S½, S112, T8S, R18E
Unnamed	SE¼, S-12, T8S, R18E

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Appendix D

Raw data for thermal features of upper and lower Aravaipa Creek, 1976-77

Appendix Table 1. Raw data for temperatures of upper Aravaipa Creek, Graham County, Arizona; starting times are marked with an asterisk (*).

Times	Starting Dates													
	760809	761119	770111	770218	770316	770422	770605	770709	770820	770915	771020	771202	771212	780218
0600			10.8	11.5				18.5						
0630	17.7				11.5		17.5		19.5	17.0	13.7			10.5
0700		11.3						19.0					10.5	
0730	17.8					14.0			21.0			11.0		10.5
0800		13.1	10.9	11.5				19.6						
0830	19.6				12.0	15.0	19.0		21.6	18.5	14.5	11.5		11.0
0900			10.5	11.5				20.5					11.0	
0930					12.5	15.7	20.5		22.5	20.8	16.7			12.0
1000		15.0	12.0	12.5				22.0				13.1	12.0	
1030	25.0				14.0	16.5	22.0		22.7	23.6	19.0			
1100		16.5	13.4	14.5				23.5					13.7	
1130	27.7				14.5	17.5	23.0		23.5	24.8	21.0			15.7
1200		17.7	13.5					24.5				17.0	15.7	
1230	28.4	18.5*			15.0	17.6	24.5		29.0*	25.5	22.5*			16.5
1300			14.0*	18.0				25.2						
1330		18.0			16.0	17.6	25.0		32.0		22.4			17.5
1400	27.5		14.4	18.5				25.5				18.2		
1430	26.3*	16.2			16.9	17.6	23.0		32.0	25.2	22.1		17.0*	18.1
1500			14.0	18.5				25.5						
1530	25.5	16.0			16.5	18.0			30.0		20.5		16.2	18.0
1600			13.0	17.0				25.0						
1630	25.0	15.6			15.2	18.0	21.0		27.8	22.7	19.1	15.1*	14.8	16.2
1700			12.8	15.5				24.0						
1730		15.0			14.5	17.6	20.5		26.5	20.7*	17.5	14.4	14.0	13.5*
1800			12.6	15.0				23.0						
1830	23.3	15.0			13.5	18.2*	19.5		24.0	20.0	17.0	13.7	13.9	13.0
1900			12.4	14.5				22.0						
1930					13.2	17.0	19.0		23.0	19.5	16.5		13.4	12.7
2000	22.2		11.6	13.5*				21.0*						
2030		13.8			13.0	17.0	19.0		22.3	19.0	16.5	13.0	13.0	
2100	21.5			13.0				20.5						12.5
2130					12.1	16.3	18.0*							12.5
2200			11.6	12.7				20.0		18.5	16.1			
2230		13.0			12.0	16.0	18.0							12.5
2300	20.6			12.7				20.0		18.0				
2330					13.0*		18.0							
2400	20.5	12.5	11.6	12.4					22.0	17.6				
0030												11.9		12.0
0100						15.0	17.5			17.5	15.0			
0130														
0200														
0230	19.5													
0300		11.5											11.2	
0330				12.0	11.5									11.0
0400	18.5					14.0	17.0			17.3	14.5			
0430								18.9						
0500		11.0												
0530	18.5								19.7					

Appendix Table 2. Raw data for temperatures of lower Aravaipa Creek, Pinal County, Arizona; starting times are marked with an asterisk (*).

Times	Starting Dates													
	761023	761120	770115	770119	770318	770423	770606	770710	770816	770916	771022	771203	771209	780127
0600		9.8							22.5	18.5	12.7			
0630												7.9	8.6	9.3
0700			4.6	9.0		15.5				18.5	12.4			
0730	12.9				7.5				22.7*			7.0		9.1
0800		9.8	4.2	9.0				23.1		18.6	12.4			
0830					7.5		21.0*		23.4				8.8	9.0
0900	12.7	10.6	4.5	9.5		16.0		24.0			12.7	7.0		
0930					8.5		22.5		25.5					
1000		11.2	4.6	12.0		16.6		25.5			13.6			9.5
1030	14.4				10.1		25.0		26.3				9.7	
1100		13.7	6.0	14.0		17.5		27.0		23.8	15.6			12.0
1130					12.0		25.0		31.3				10.7	
1200	16.6	15.7	8.0	16.0		17.5		29.5		25.5	17.4	10.5		
1230					14.2		25.5						11.8	13.0
1300		17.3	9.7	18.5		17.7		30.0	33.2	27.7	19.3			
1330	20.3*						26.0						13.1	13.6
1400		18.0	10.9	19.8		18.0		30.8	33.5	28.5	20.0	12.8		
1430							27.0						13.8	14.4
1500		18.0	11.5	20.5		18.3		30.0	32.0	28.0	20.5	12.7		
1530							27.5						13.1	13.7
1600		17.2	10.8	19.8		18.5		28.5	29.3	25.8		11.9	12.9	
1630	18.5				16.5*		25.5							12.1*
1700		16.1	9.0*	18.5		18.6		27.5	27.8	24.5			12.1	
1730					15.5		25.0		27.0					11.6
1800		15.0	7.0	17.0		17.6			26.2	23.5	17.6*			
1830					14.3		24.0		24.7					11.2
1900		14.5*	8.0	15.5		17.5		26.5	23.7	22.5	17.0	9.6*		
1930					13.1		23.5		24.0				10.0*	11.2
2000		14.0	7.5	14.0				26.0	24.0	21.8	16.6	9.6		
2030	16.1				12.2		22.5						9.5	11.1
2100			7.9	13.5				25.9	23.5			9.4		
2130					11.5								9.5	10.8
2200		12.9	6.5	13.0		16.5*		25.5	23.5		15.5	9.1		
2230					11.0								9.5	10.6
2300			6.5	11.6*		16.5		25.0*	23.5	20.6*		9.0		
2330													9.3	10.5
2400		12.0	6.0	11.5	10.5	16.0		24.5		19.5	14.8			
0030	14.6												9.3	10.5
0100			6.2			16.0		23.5						
0130														
0200								23.0	23.5			8.1		
0230														
0300		10.7	5.5							19.5	13.5			
0330													9.0	10.0
0400						15.5			22.5					
0430														
0500				9.5				22.6	22.5					
0530	12.9													

APPENDIX E

FEEDING INTERRELATIONSHIPS OF FISHES OF ARAVAIPA CREEK, ARIZONA

by

Donald Clifford Schreiber

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

ARIZONA STATE UNIVERSITY

December 1978

FEEDING INTERRELATIONSHIPS OF FISHES OF ARAVAIPA CREEK, ARIZONA

by

Donald Clifford Schreiber

has been approved

October 1978

APPROVED:

, Chairperson

Supervisory Committee

ACCEPTED:

R. H. Alvarado
Department Chairperson

Kenneth A. Carey
Dean, Graduate College

ABSTRACT

Food habits of seven native species of fishes were examined over a 13-month period in Aravaipa Creek, Graham County, Arizona. Availability of foods to the fishes was estimated by sampling benthic communities and stream drift. Three trophic patterns were presented: herbivory by a mountain-sucker (Pantosteus clarki); omnivory by longfin dace (Agosia chrysogaster); and carnivory by the remaining five species (Gila robusta, Meda fulgida, Rhinichthys osculus, Tiaroga cobitis, and Catostomus insignis). Ephemeropteran nymphs were the predominant food of the carnivorous fishes, and of the omnivore, and were the dominant invertebrate in both benthos and drift. When absolute densities and average individual body sizes of mayfly nymphs decreased dramatically, three fish species each shifted to a different alternate prey, and three others did not obviously respond. (One species, G. robusta, was not studied quantitatively.) Fishes which responded to alternate prey increased special feeding behavior and spatial partitioning of habitat. Those which did not respond remained as generalized feeders. Interspecific interactions related to feeding habits are probably minimal in Aravaipa Creek because of the abundance of food organisms and spatial segregation of the fishes.

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Useful information and assistance was provided by residents of the study area, and by personnel of the U. S. Bureau of Land Management and the Defenders of Wildlife. Both the last agencies provided continued access to the study site, and supplied funds that supported parts of my research.

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INTRODUCTION

Native fishes in arid parts of western North America are suffering rapid declines in populations and vast reductions in range. Man causes most of these changes through continuous manipulation and re-working of aquatic habitats, and many persons and agencies are alarmed by the situation. Miller (1961) and Minckley and Deacon (1968) provided perceptive discussions of this subject. Increased effort is being put forth by many workers to learn more about these threatened animals, and what they will require to successfully maintain themselves (Pister 1974).

Aravaipa Creek in south central Arizona presents a rather unique situation. Seven species of native fishes reside in the stream, in a pattern once common throughout the region. There they co-exist, under natural conditions, largely undisturbed by foreign influences. Only one non-native species, the green sunfish (Lepomis cyanellus Rafinesque) has been successful in maintaining a small, local population within the system.

Some information has appeared relative to Aravaipa Creek fishes. Barber and Minckley (1966) published a general account of the ichthyofauna, Barber et al. (1970) presented data on biology of the spikedace (Meda fulgida Girard), and Minckley and Barber (1971) included information from Aravaipa Creek in their general paper on ecology of longfin dace (Agosia chrysogaster Girard). Minckley (1973) and Deacon and Minckley (1974) discussed many general aspects of the ecology of the stream and its fishes.

The purpose of my study was to obtain information on foods and feeding of native fish species in Aravaipa Creek. Fishes concerned, in

addition to spikedace and longfin dace mentioned above, included two catostomids, Catostomus insignis Baird and Girard (Gila coarse-scaled sucker) and Pantosteus clarki (Baird and Girard) (Gila mountain-sucker), and two additional cyprinids, Rhinichthys osculus Girard (speckled dace), and Tiaroga cobitis Girard (loach minnow). The seventh native fish of the drainage, Gila robusta Baird and Girard (Colorado River chub), was too rare during my period of study to allow adequate sampling. Data on its food habits were determined from specimens taken over a long period of time (1965-78) and housed in the Arizona State University Collection of Fishes, and were provided by James Burton of that institution.

Along with determination of how and what the fishes ate, I explored the question of food availability within the environment. Estimates of population densities and biomasses of the various potential and actual food items were made, and from these data determinations were made as to how selective, or vice versa how opportunistic, the fishes were in their feeding.

DESCRIPTION OF THE STUDY AREA

Aravaipa Creek is in Graham and Pinal counties, Arizona, in the San Pedro River drainage (Gila River system; Fig. 1). The channel originates between the Pinaleño and Galiuro mountains, running first northwest then turning west, for a distance of more than 100 kilometers (km). Much of the stream bed is usually dry, with permanent water first rising from gravels at about 1,010 meters (m) above mean sea level, 6.2 km northwest of Klondyke. Within a short distance, near the inflow of Turkey Creek (Fig. 1), the mainstream enters a gorge, named Aravaipa Canyon, to

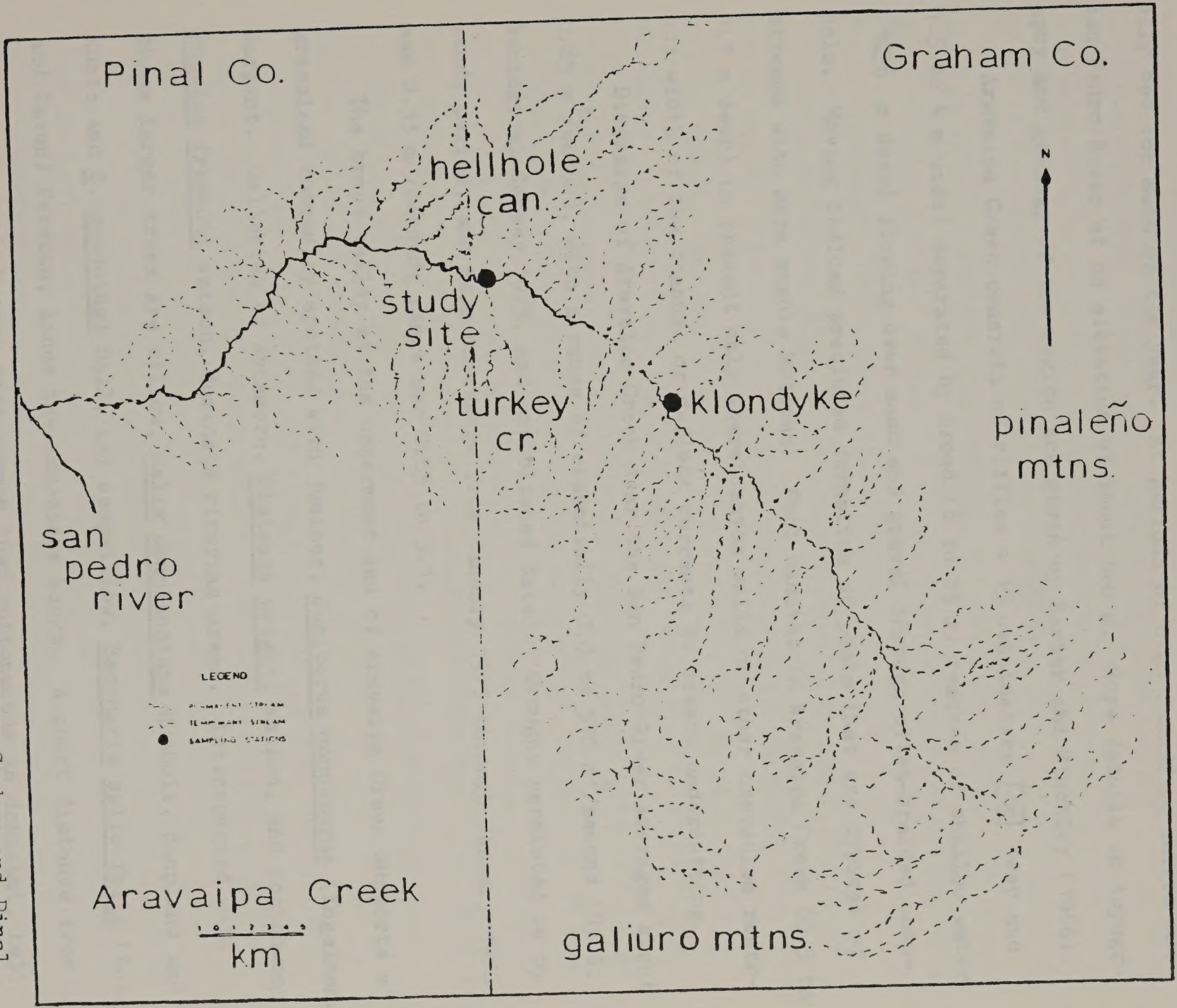

Fig. 1. Sketch map of the Aravaipa Creek drainage, Graham and Pinal counties, Arizona, showing features mentioned in text.

flow between stony cliffs for about 30 km. Below the gorge, the creek passes through an ever-broadening valley to disappear back into its gravelly bed for much of the year. At periods of high runoff it enters the San Pedro River at an elevation of about 660 m. More details on topography and geology of the region are given by Barber and Minckley (1966).

Aravaipa Creek consists of riffles = 15 centimeters [cm] deep and 1.5 to 4 m wide) separated by broad (8 to 15 m) reaches of shallow water ($<$6 m deep) flowing over sand and gravel through often-braided channels. Moving bedload precludes formation of pools that are typical of streams with more stable bottoms. Pool habitat in Aravaipa Creek (0.5 to 1.5 m deep) is present only where canyon walls or other obstacles restrict width of the channel or deflect currents to create undercutting.

Discharge of Aravaipa Creek near the San Pedro River averages about 0.85 m^3/second, with a range of essentially 0.0 to 570 m^3/second (U. S. Geological Survey 1975, and unpublished data). Drought persisted in my study period, and mean discharge from January 1975 through January 1976 was 0.33 m^3/second; range was 0.05 to 3.1.

The broad valley at the uppermost end of Aravaipa Creek supports a grassland community spotted with juniper, *Juniperus monosperma* (Engelmann) Sargent. Galleries of sycamore, *Platanus wrighti* Watson, and cottonwood, *Populus fremonti* Watson, dominate riparian areas. Interspersed with these larger trees are willow, *Salix bonplandiana* Humbolt, Bonpland and Kuntz and *S. gooddingi* Ball, and seepwillow, *Baccharis salicifolia* (Ruiz and Pavon) Persoon, lines the immediate banks. A short distance from water, sycamores become more common than cottonwoods as dominant, tall trees. Dense stands of mesquite, *Prosopis juliflora* (Swartz) de Candolle

are on drier terrace habitat and areas where floodplains have not been cleared for pasture or other agricultural uses.

Within Aravaipa Canyon, where tributaries enter the main gorge, terraces support a diverse flora. Cottonwoods remain common, with sycamore present a few meters from water. Mixed with the latter are ash, Fraxinus velutina Torrey, boxelder, Acer negundo Linnaeus, and walnut, Juglans major (Torrey) Heller. Within the gorge, these species are scattered on narrow strips of terrace along canyon walls.

Hellhole Canyon (Fig. 1) marks the transition to Lower Sonoran Desert as one moves downstream. Saguaro cactus, Cereus giganteus Engelmann, cholla, Opuntia fulgida Engelmann, and prickly pear, O. phaeacantha Engelmann, creosote bush, Larrea divaricata Cavanilles, and palo verde trees, Cercidium floridum Bentham and C. microphyllum (Torrey) Rose and Johnston, dominate uplands. Cottonwood remains the major riparian tree. As the gorge opens to the lower valley, cottonwood becomes a gallery forest, and sycamore is infrequent in company with dense mesquite, hackberry Celtis reticulata Torrey and C. pallida Torrey, and other, more xeric-adapted trees and shrubs along terraces.

Watercress, Nasturtium officinale R. Brown, is the only important aquatic vascular plant along Aravaipa Creek, occurring commonly from the source to about Turkey Creek, and rarely elsewhere.

Location of Aravaipa Creek in southwestern desert is reflected by high ambient temperatures and little precipitation. Air temperatures range from less than 5° to more than 40° Celsius. January is the coolest month and June - July are warmest. Precipitation varies from year to year, ranging from 19.4 to 54.9 cm at Klondyke. Summer storms produce

the greatest amounts of rainfall, in July and August, while spring months (April - May) tend to be periods of drought (Sellers and Hill 1974).

Selection of a sampling area was dictated by the abundance of fishes and the consistent presence of a maximum number of species. The segment of Aravaipa Creek near the inflow of Turkey Creek was diversified, consisting of a riffle about 60 m long, bounded up- and downstream by broad, shallow areas with sand-gravel bottom. Pool habitat was provided where the creek was deflected from a canyon wall (Figs. 2 - 3). The stream flowed from northeast to southwest at this point, with the right side (facing downstream) consisting of a vertical cliff, and the low bank on the left side vegetated by willows and interspersed cottonwoods. Widths of the flowing channel and depths of various habitats changed with discharge, but closely resembled average conditions given earlier for the overall stream.

METHODS AND MATERIALS

Field collections of fishes and drifting materials were made over five, two-day intervals: 9 - 10 January; 18 - 19 April; 11 - 12 July 24 - 25 October 1975; and 30 - 31 January 1976.

Fishes were sampled by seines or electrofishing equipment. Seines were 9.5 m long, with 6.4 millimeter (mm) mesh (bar measure), and electrofishing gear was 110 volts, 1,200 watts, alternating current. Number of fish preserved every four hours was limited to a maximum of 5 - 10 individuals per speices, to avoid deplition of local stocks over a 28 - hour period. Most fish sampling was done downstream from the drift and benthos site, with a few collections taken 400 m upstream. Fishes

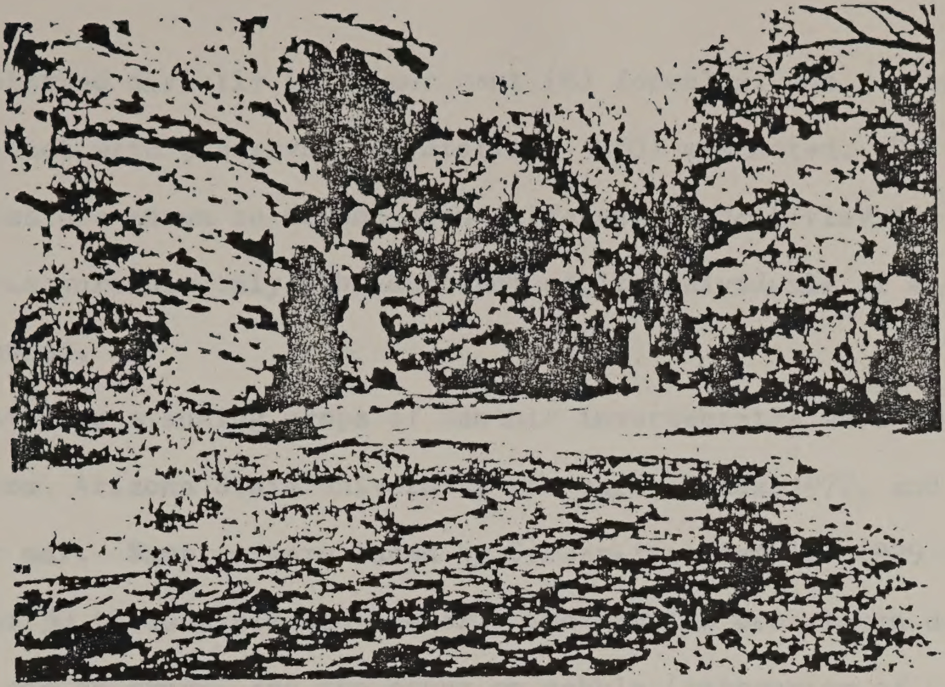

Fig. 2. Aravaipa Creek, Graham County, Arizona. View upstream at study site, with drift sampler in place. Pool habitat was present at the base of the cliff in left center, separated from the riffle in foreground by a sand-gravel run; photograph by the author, January 1975.

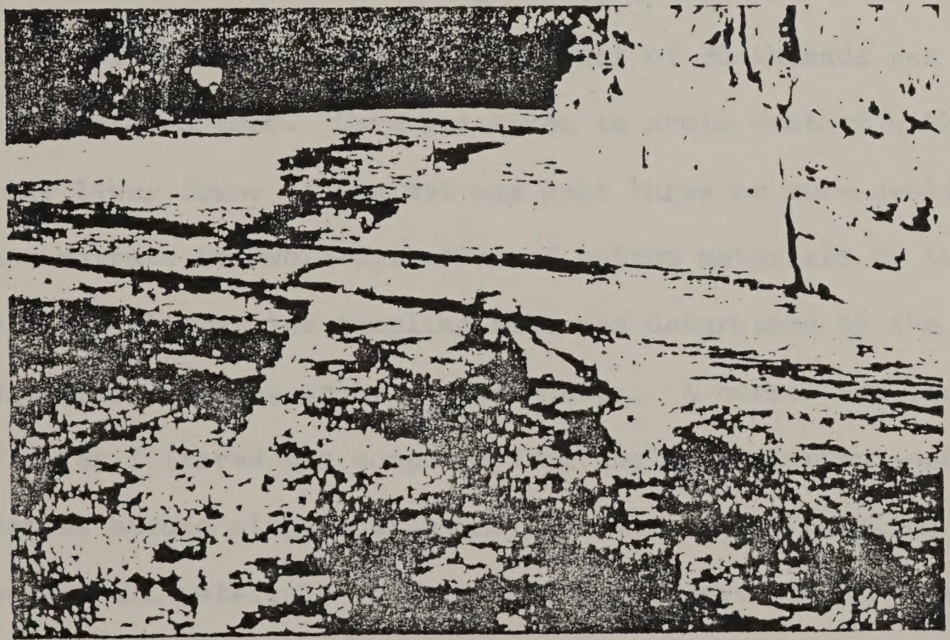

Fig. 3. Aravaipa Creek, Graham County, Arizona. Stream deflecting from canyon wall to create pool habitat at cliff shown in Fig. 2; photograph by Steven Burton, January 1977.

were preserved directly in 10 per cent (%) formalin. No regurgitation upon contact with preservative (Starrett 1950) was noted. Different sized fish are known to depend upon different foods (Ivlev 1961), and to avoid this variable only sub-adult and adult individuals of each species were studied.

Data for standing crops of benthic invertebrates were provided by Dale Bruns, Arizona State University (in part, Bruns 1977, and Bruns and Minckley ms). Samples were taken by Surber-type sampler (929 cm^2), with a mesh of 30 threads per centimeter. Two samples were taken during each period, one on gravel and the other on cobble (categories of Cummins 1962). All materials collected were preserved in the field in 10% formalin.

The drifting component of potential and actual food for fishes was sampled immediately prior to each fish collection, over the same 28-hour periods. Two sections of reinforcing rod were driven into the stream bed in the center of the channel, and a drift net of 30 threads per centimeter was tethered between them. Care was taken to avoid contact with the bottom, and the lower frame of the net was kept three or more centimeters above the substrate to avoid agitation of bottom materials by turbulence. Speed of flow at the sampling site was determined by the Embody (1929) cork-float method, or by current meter. A correction factor for volume of water filtered was computed from declining current-meter readings as meshes became clogged with various materials. Sampling was for 15 minutes and all materials collected were preserved in 10% formalin.

Food habits of fishes were determined by removal of stomachs or of the digestive tract anterior to the first loop toward the head in those species with poorly defined stomachs (catostomids). Contents were

placed in a gridded Petri dish, and sorted to taxonomic categories. Invertebrates were identified to family if possible. Other categories were inorganic materials (mostly sand), finely divided organic material (detritus), filamentous algae, and diatoms. The volume of stomach occupied by each item was estimated by sight using Hynes' (1950) point system. Each item in a stomach was assigned a point value from greater than 0.0 to a maximum of 20.0, with the latter indicating that 100% of stomach contents was represented by that item, and that the stomach was full. Each point therefore was equivalent to 5.0% of the total estimated stomach volume. Empty stomachs were scored 0.0 points, and were included in compilations that follow.

As an example, if it were estimated that 40% of a stomach was filled, it would be assigned 8.0 points. If three items were present, an assignment of points to each would be made, depending upon the volume each occupied, but the sum of points could not exceed 8.0. Relative strengths and weaknesses of this technique are detailed by Hynes (1950) and Corbet (1961), who found estimation of relative volumes did not differ significantly from methods where quantities were measured directly. Actual volumes of items or parts of items present were assigned points; no attempt was made to reconstruct live volumes of invertebrates from fragments present (Ricker 1937).

Benthos and drift samples were sorted into the major categories as given before for stomach contents. Leaves and other large, terrestrial vegetative materials were hand picked. Remaining organic components were separated from inorganic materials by an elutriation column similar to that described by Lauff et al. (1961). After inspection for dense

biologic items such as trichopteran cases, inorganic materials were discarded.

Algae were typically rare in drift, but far more common in benthos samples; filaments and clumps were hand picked. Obvious presence of diatoms was simply noted.

Fine, particulate detritus and invertebrates often were abundant, and were subsampled by Folsum Plankton Splitter prior to sorting. The subsamples were placed in gridded Petri dishes, and invertebrates were hand picked. Detritus remained as the last category upon removal of invertebrates. Subsamples were determined to estimate densities within limits of precision deemed acceptable by Elliott (1971).

After identification and enumeration of invertebrates, they and other organic materials were blotted dry and weighed in grams (g) or milligrams (mg) on a Mettler Electric Analytical Balance. Data on benthos were converted to numbers or g/m^2 by direct proportion. Drift was converted to numbers or mg/m^3 by use of the following formula:

$$D_1 \text{ or } D_2 = \frac{N \text{ or } W/T}{NF \quad X \quad V} \quad X \quad CF,$$

where D_1 is number or D_2 is mg/m^3, N is number of organisms or W is milligrams collected per unit time (T), NF is net face area (m^2), V is velocity of water in m/second, and CF is a conversion factor derived from current meter readings.

Marked periodicity of drift of aquatic invertebrates (Waters 1962), and in feeding of fishes (Ivlev 1961), was compensated for by computing means for each over the 28-hour sampling periods. Standing crops of benthos were considered as being represented by the mean of two samples

taken per sampling period. Compilation of data was performed on a Univac 1110/42 computing system at the Arizona State University Computing Center.

RESULTS

Foods Available to Fishes

In early studies of foods and feeding of fishes, invertebrates eaten were generally divided as "benthic" or "terrestrial" in origin. Benthic organisms were those presumably picked up by the fish from the substrate. Terrestrial kinds often included adults of aquatic forms, plus aerial, plant dwelling, or riparian species that were taken from the water surface.

Sampling of prey organisms, when attempted, most often consisted of an assessment of standing crops of benthic invertebrates alone (Surber 1936, Mottley *et al*. 1939, Hess and Schwartz 1941). However, Needham (1928) had already demonstrated downstream drift of both aquatic and terrestrial insects as food supplies for stream fishes. Denham (1939) finally recognized that downstream drift of aquatic insect larvae was a basic pattern of their ecology. Since that time, quantification of drift as an adjunct to bottom sampling in determining foods available to fishes has increased in frequency (see Waters 1972).

A total of 75 potential or actual food items was taken in samples of benthos, drift, and fish stomachs from Aravaipa Creek (Table 1). Of these, 69 (29%) were invertebrates. Vertebrates (three species) were eaten only by Colorado River chub, and actual diversity of plant material was not assessed. Inorganic material (sand) was excluded from the gross number of items, but was of common occurrence in stomachs of *Pantosteus*

Table 1. Occurrence of potential and actual food items in samples of benthos, drift, and fish stomachs from Aravaipa Creek, Arizona, on five sampling dates in 1975-76. The symbol "X" denotes presence of the item on a given date, "-" indicates its absence, and occurrence of items in stomachs of *Gila robusta*, based on data provided by James Burton (see text), is denoted by the symbol "+".

Items	Benthos	Drift	*Gila*	*Agosia*	*Meda*	*Rhinichthys*	*Tiaroga*	*Catostomus*	*Pantosteus*
COLLEMBOLA									
Undetermined taxa	-----	XXXXX	-	-----	-----	-----	-----	-----	-----
Sminthuridae	-----	X----	-	-----	-----	-----	-----	-----	-----
EPHEMEROPTERA									
Undetermined adults	-----	XXXXX	-	---XX	-X-XX	-----	-----	-----	-----
Baetidae nymphs	XXXXX	XXXXX	+	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Tricorythidae nymphs	XXXXX	XXXXX	+	XXXXX	XXXXX	-X-XX	--XXX	XXXXX	--XX-
Heptageniidae nymphs	X---X	X---X	-	X---X	X----	X----	-----	X----	-----
Leptophlebiidae nymphs	XXXXX	XXXXX	+	X XX-	XXXX-	-X---	-X---	-X---	--X--
Ephemerellidae nymphs	-X--X	-X---	-	-X---	-X---	-X---	-X---	-X---	-----
PLECOPTERA									
Capniidae adults	----	X---X	-	X----	X----	-----	-----	X----	-----
Capniidae nymphs	X--XX	XX-XX	-	X---X	X--XX	X---X	X----	X--X-	X--X-
ODONATA									
Gomphidae nymphs	---XX	X-XX-	+	---X-	-----	-----	-----	X-XXX	-----
Libellulidae nymphs	---XX	-----	+	-----	-----	-----	-----	-----	-----

Table 1. Continued.	Benthos	Drift	Gila	Agosia	Meda	Rhinichthys	Tiaroga	Catostomus	Pantosteus
HEMIPTERA									
Undetermined terrestrial taxa	-----	XXXXX	-	-----	--XX-	-----	-----	-----	-----
Belostomatidae	-----	-----	+	-----	-----	-----	-----	-----	-----
Corixidae	----X	XXXXX	-	---X-	--X--	-----	-----	-----	-----
Mesoveliidae	-----	X-XXX	-	-----	-X---	--X--	-----	-----	-----
Microveliidae	-----	----X	-	---X-	-X---	-----	-----	-----	-----
Rhagoveliidae	---X-	-----	-	---X-	-----	-----	-----	--X--	-----
THYSANOPTERA									
Thripidae	-----	XXXX-	-	-----	-----	-----	-----	-----	-----
HOMOPTERA									
Undetermined taxa	-----	---X-	-	---XX	-XXXX	-----	-----	-----	-----
Aphididae	-----	XXXXX	-	-X---	--XX-	-----	-----	-----	-----
Cercopidae	-----	-----	-	---X-	---XX	-----	-----	-----	-----
TRICHOPTERA									
Undetermined adults	-----	--X-X	-	-----	--XXX	--X-X	---X-	-----	XX---
Helocopsychidae larvae	--X--	-----	-	-----	-----	-----	-----	-----	-----
Hydropsychidae larvae	X-XXX	-XXXX	+	-XXXX	--XXX	-XXXX	--XXX	XXXXX	----X
Glossosomatidae larvae	--XXX	--XXX	-	--XX-	--XX-	--XX-	--X--	-XXXX	--X--
Hydroptilidae larvae	X-X-X	-X---	+	-----	-----	-----	-----	-XXX-	-----
Limnophilidae leavae	--X--	-----	-	-----	-----	-----	-----	-----	-----
DIPTERA									
Chironomidae adults	-----	XXXXX	-	XXXXX	X-XXX	---X-	-----	X--X-	X----

Table 1. Continued.	Benthos	Drift	Gila	Agosia	Meda	Rhin-ichthys	Tiaroga	Catos-tomus	Pant-osteus
DIPTERA (Continued)									
Chironomidae larvae and pupae	XXXXX	XXXXX	+	XXXXX	-XXXX	XXXXX	XXXXX	XXXXX	XXXXX
Simuliidae adults	-----	XX-XX	-	--X--	-X-X-	-----	-----	-----	-----
Simuliidae larvae and pupae	XXXXX	XXXXX	+	XXX-X	XXXXX	XXXX-	XXXXX	XXXXX	XXXXX
Tabanidae larvae	--X--	-----	-	--X--	-----	-----	---X-	---XX	-----
Ceratopogonidae larvae	XXX--	XXXX-	-	X----	X-X--	-XX--	-----	X-X-X	-----
Tipulidae adults	-----	-----	-	-----	-----	---X--	-----	-----	-----
Tipulidae larvae	-----	X----	-	X----	X-X--	-----	-----	---X-	-----
Dixidae larvae	----X	XX-X-	-	XX---	--X--	-X---	-----	-----	-----
Ephydridae larvae	X----	X---X	-	X----	X--XX	-----	-----	X--XX	-----
Muscidae larvae	---X-	-----	-	X----	-----	-----	-----	-----	-----
Stratiomyiidae larvae	-----	--X-X	-	--X--	-----	--X--	-----	---XX	-----
Empididae larvae	----X	X----	-	-----	-----	-----	-----	X---X	-----
Culicidae larvae	-----	X--X-	-	----X	--X--	-----	-----	---X-	-----
LEPIDOPTERA									
Undetermined terrestrial adult	-----	-----	-	-----	-----	-----	-----	---X-	-----
Pyralidae larvae	-X---	-X-X-	-	----X	--X--	-----	-----	---X-	-----
MEGALOPTERA									
Corydalidae larvae	----X	-----	-	-----	--X--	-----	-----	--X--	-----
COLEOPTERA									
Undetermined terrestrial adults	-----	XXXX-	-	--XX-	--XX-	----X	-----	-----	-----
Curculionidae adults	-----	-----	-	-----	-----	-----	-----	---X-	-----

Table 1. Continued.	Benthos	Drift	Gila	Agosia	Meda	Rhinichthys	Tiaroga	Catostomus	Pantosteus
COLEOPTERA (Continued)									
Hydrophilidae adults	-----	X-X--	+	-----	-----	-----	-----	-----	-----
Elmidae larvae	----X	X-XX-	-	-----	-----	-----	-----	--X-X	-----
Dytiscidae larvae	-----	X--X-	+	X---X	-----	-----	-----	XX---	-----
Staphylinidae adults	-----	--XX-	-	-----	--X--	-----	-----	-----	-----
Halipidae larvae	-----	XX---	+	--X--	-----	-----	-----	-----	-----
Dryopidae adults	-----	-----	+	-----	-----	-----	-----	-----	-----
HYMENOPTERA									
Undetermined terrestrial taxa	-----	-----	-	-----	--X--	-----	-----	-----	-----
Ichneumonidae	-----	-----	X	-----	-----	-----	-----	-----	-----
Chalcidoidea	-----	XXXX-	-	-----	-----	-----	-----	-----	-----
Formicidae	-----	X-X--	+	-----	--X--	-----	-----	-----	-----
MALLOPHAGA									
Undetermined terrestrial taxa	-----	-XXX-	-	-X---	-----	-----	-----	-----	-----
ACARINA									
Undetermined taxa	XXXXX	XXXXX	-	-----	-----	--X--	-----	X-XXX	-X---
ARANEIDA									
Undetermined taxa	-----	--X--	-	-----	-----	-----	-----	----X	-----
CRUSTACEA									
Ostracoda (Cypridae)	--XXX	XXXXX	-	XXX-X	-----	--X--	-----	XXX-X	X----
Cladocera (Chydoridae)	-----	-XX-X	-	-----	-----	-----	-----	----X	-----
Copepoda (Cyclopoidea)	-----	XXXXX	-	-----	-----	-----	-----	--X--	-----

Table 1. Concluded	Benthus	Drift	Gila	Agosia	Meda	Rhin-ichthys	Tiaroga	Catos-tomus	Pant-osteus
TARDIGRADA									
Undetermined terrestrial taxa	-----	-X---	-	-----	-----	-----	-----	-----	-----
ANNELIDA									
Undetermined Oligochaeta taxa	XX-XX	XXXXX	-	--X--	-X---	-----	-----	--X--	--X--
Undetermined Hirudinea taxa	--X--	-----	-	-----	-----	-----	-----	-----	-----
NEMATODA									
Undetermined taxa	X---X	XX---	-	XX---	-XX--	--X--	-----	XXX-X	-XXXX
TURBELLARIA									
Planariidae	--X--	-----	-	-----	-----	-----	-----	XXXXX	--X-X
HYDRAZOA									
Hydridae	----X	XXX-X	-	-----	-----	-----	-----	-----	-----
VERTEBRATA									
Meda fulgida	-----	-----	+	-----	-----	-----	-----	-----	-----
Agosia chrysogaster	-----	-----	+	-----	-----	-----	-----	-----	-----
Sceloporus magister	-----	-----	+	-----	-----	-----	-----	-----	-----
PLANT MATERIALS									
Diatoms	XXXXX	XXXXX	-	-XXXX	-----	-----	-----	-----	XXXXX
Filamentous algae	XXXXX	XXXXX	+	XXXXX	X----	X-X--	-----	----X	--XXX
Detritus	XXXXX	XXXXX	+	XXXXX	---XX	--XX-	-----	X--XX	---X-
INORGANIC MATERIALS									
Sand	Na.[1]	Na.	+	-XXX-	-----	--XX-	-----	----X	XXXXX

---

[1] Na. = not applicable.

clarki, and was occasional in *Agosia chrysogaster*, *Rhinichthys osculus*, and *Catostomus insignis*.

Of invertebrate taxa recorded, 36 kinds (52.2%) were nymphs, pupae, or non-emerging adults of aquatic insects. Non-insect aquatic animals made up 13% (9 groups), emergent adults of aquatic groups, 8.7% (6 groups), and 26.1% (18 taxa) were of terrestrial origin.

Only a few invertebrate taxa were consistently present in both benthos and drift samples (Tables 2 - 3). Mayfly genera of the family Baetidae (*Baetis*, *Callibaetis*, and *Centroptilium*) comprised most biomass of ephemeropteran nymphs, and were dominant by numbers. Tricorythid nymphs (*Tricorythodes*) and Lepthophlebiidae (*Choroterpes* and *Leptohypes*) were far less abundant than baetids, but were equally as frequent in occurrence. Heptageniid (*Rithrogena*) and ephemerellid (*Ephemerella*) nymphs were abundant seasonally (winter-spring) in benthos samples (Table 2), and were present in drift during the same periods (Table 3).

Larvae and pupae of the dipteran families Chironomidae and Simuliidae were present in all periods, both in drift and benthic samples. They were relatively important in terms of biomass, and were often present in large numbers (Tables 2 - 3). Chironomid adults were present in all drift samples, forming significant proportions of biomass (Table 3). Simuliid adults were uncommon in drift, but were taken in 4 of 5 sampling periods (Table 1).

Water mites (Acarina) were in all benthic and drift samples (Tables 1 - 3), but numbers and weights comprised a miniscule percentage of totals recorded. Microcrustaceans, especially cyprid ostracods, also were relatively consistent in occurrence, but of minor consequence in biomass.

Table 2. Numbers and biomass (g/m^2, wet weight) of potential and actual food items of fishes in benthos samples from Aravaipa Creek, Arizona, 1975-76. Items which did not occur as at least 1.0% in averages of at least one sampling period are lumped as "other" (see also Table 1).

Items	Sampling Periods									
	January		April		July		October		January	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
EPHEMEROPTERA										
Baetidae	565	0.56	1,851	1.67	1,453	0.82	4,930	2.56	3,552	1.11
Tricorythidae	215	0.13	474	0.38	215	0.11	388	0.07	215	0.07
Heptageniidae	22	0.01	---	---	---	---	---	---	301	1.87
Leptophlebiidae	172	0.12	172	0.09	581	0.25	797	0.24	1,033	0.49
Ephemerellidae	---	---	431	0.57	---	---	---	---	65	0.03
PLECOPTERA										
Capniidae	32	0.01	---	---	---	---	129	0.02	22	Tr.[1/]
HEMIPTERA										
Rhagoveliidae	---	---	---	---	---	---	22	0.12	---	---
TRICHOPTERA										
Helicopsychidae	---	---	---	---	22	0.02	---	---	---	---
Hydropsychidae	11	0.01	---	---	43	0.05	1,313	1.26	1,313	10.72
Glossosomatidae	---	---	---	---	97	0.06	22	0.03	258	0.07
Hydroptilidae	11	0.01	000	000	65	0.01	55	0.01	65	0.01

Table 2. Continued.	January		April		July		October		January	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
DIPTERA										
Chironomidae	2,594	0.18	4,435	0.60	958	0.07	775	0.10	3,488	0.62
Simuliidae	118	0.01	172	0.03	54	0.01	1,658	0.21	1,830	0.27
Tabanidae	---	---	---	---	11	0.22	---	---	---	---
Ceratopogonidae	22	0.01	301	0.10	75	0.02	---	---	---	---
Ephydridae	64	0.01	---	---	---	---	---	---	---	---
MEGALOPTERA										
Corydalidae	---	---	---	---	---	---	---	---	16	0.99
ACARINA										
Undetermined taxa	43	0.01	43	0.01	22	Tr.	43	0.02	248	0.05
CRUSTACEA										
Ostracoda (Cypridae)	---	---	---	---	226	0.13	172	0.10	301	0.10
ANNELIDA										
Undetermined Oligochaeta taxa	205	Tr.	1,550	0.02	---	---	43	0.80	140	0.49
TURBELLARIA										
Planariidae	---	---	---	---	54	0.16	---	---	---	---
OTHER ITEMS										
Other aquatic taxa[2/]	32	Tr.	44	Tr.	311	0.02	278	0.16	452	0.14
PLANT MATERIALS										
Diatoms	Na.[3/]	Tr.	Na.	Tr.	Na.	---	Na.	Tr.	Na.	Tr.
Filamentous algae[4/]	Na.	5.23	Na.	57.27	Na.	0.97	Na.	Tr.	Na.	26.91

Table 2. Concluded.	January		April		July		October		January	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
PLANT MATERIALS (Continued)										
Detritus[5]	Na.	7.31	Na.	4.04	Na.	8.37	Na.	23.22	Na.	Tr.
TOTALS										
Excluding plant materials	4,096	1.09	9,473	3.47	3,897	1.95	10,398	5.59	12,933	16.92
Including plant materials	Na.	13.63	Na.	65.98	Na.	11.29	Na.	28.81	Na.	49.73

---

[1] Tr. = less than 0.005 g/m^2

[2] Including for present purposes: ODONATA - Gomphidae and Libellulidae; HEMIPTERA - Corixidae; TRICHOPTERA - Limnephilidae; DIPTERA -Dixidae, Muscidae, and Empididae; LEPIDOPTERA - Pyralidae; COLEOPTERA - Elmidae; ANNELIDA - Undetermined Hirudineantaxa; NEMATODA - Undetermined taxa; and HYDRAZOA - Hydridae.

[3] Na. = Not applicable.

[4] Data are means of 8 – 15 samples taken throughout the stream relative to another study (Bruns and Minckley ms). Actual standing crop of filamentous algae in July was much higher than indicated on the date of sampling, and the mean value was suppressed by flooding over the next few days.

[5] Leaf litter was not included; data represent means of a number of samples as in footnote 4.

Table 3. Numbers and biomass (mg/m^3, wet weight) of potential and actual food items of fishes in drift samples from Aravaipa Creek, Arizona, 1975-76. Items which did not occur as at least 1.0% in averages of at least one sampling period are lumped as "other", ~~(see also~~ Table 1).

Items	Sampling Periods January		April		July		October		January	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
EPHEMEROPTERA										
Undetermined adults	0.5	2.3	0.3	1.4	0.2	1.1	0.1	0.7	0.5	2.4
Baetidae nymphs	8.4	14.6	15.7	7.8	6.7	2.3	14.9	9.3	19.2	20.6
Tricorythidae nymphs	4.7	6.0	7.0	4.9	1.6	0.7	7.2	0.7	2.6	2.0
Heptageniidae nymphs	Tr.1/	0.2	---	---	---	---	---	---	0.2	1.1
Leptophlebiidae nymphs	0.2	0.2	0.2	0.4	0.7	1.7	0.3	0.1	0.3	0.6
Ephemerellidae nymphs	---	---	0.4	0.6	---	---	---	---	---	---
PLECOPTERA										
Capniidae nymphs	2.0	7.5	Tr.	Tr.	---	---	0.1	Tr.	0.1	0.5
ODONATA										
Gomphidae nymphs	0.2	0.5	---	---	0.1	0.3	0.3	1.3	---	---
HEMIPTERA										
Corixidae adults	0.2	3.0	0.4	9.9	0.1	0.7	0.3	3.3	0.2	5.0
TRICHOPTERA										
Hydropsychidae larvae	---	---	0.3	1.4	0.1	0.2	0.1	0.5	0.5	3.3
Glossosomatidae larvae	---	---	---	---	0.7	0.2	0.2	0.4	0.2	Tr.

Table 3. Continued	January		April		July		October		January	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
DIPTERA										
Chironomid adults	3.4	2.2	1.1	0.7	0.6	0.4	1.2	0.8	3.5	2.3
Chironomid larvae and pupae	14.4	7.7	7.1	4.0	2.3	1.4	3.3	1.9	4.3	2.4
Simuliidae adults	0.1	0.1	Tr.	Tr.	---	---	0.3	1.3	0.1	0.1
Simuliidae larvae	6.1	4.6	1.5	1.1	1.5	1.4	3.9	2.4	2.7	2.0
Ceratopogonidae larvae	0.6	0.5	0.1	Tr.	0.6	0.3	0.1	0.1	---	---
Ephydridae larvae	0.9	0.6	---	---	---	---	---	---	0.1	Tr.
Stratiomyiidae larvae	---	---	---	---	0.5	1.1	---	---	Tr.	Tr.
LEPIDOPTERA										
Pyralidae larvae	---	---	0.1	0.2	---	---	0.1	0.4	---	---
COLEOPTERA										
Undetermined terrestrial adults	0.1	0.1	0.1	0.1	0.1	0.9	0.3	0.4	---	---
ACARINA										
Undetermined taxa	1.1	0.1	2.5	1.0	1.5	0.2	1.1	0.1	3.7	0.3
CRUSTACEA										
Ostracoda (Cypridae)	5.7	0.2	4.3	0.4	7.8	0.8	4.6	0.2	14.9	0.5
Cladocera (Chydoridae)	---	---	39.7	0.6	Tr.	Tr.	---	---	Tr.	Tr.
Copepoda (Cyclopoidea)	2.0	0.1	2.0	0.1	1.9	Tr.	1.1	Tr.	0.5	Tr.
ANNELIDA										
Undetermined Oligochaeta taxa	1.7	4.6	3.6	6.1	0.5	0.9	0.3	0.5	0.1	0.2

Table 3. Concluded.	January		April		July		October		January	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
OTHER ANIMAL ITEMS										
Aquatic nymphs and larvae[2]	0.5	0.3	0.2	0.1	---	---	0.1	0.1	---	---
Emerged aquatic insects[3]	0.1	0.2	---	---	0.2	0.1	---	---	Tr.	0.1
Terrestrial insects[4]	0.2	0.1	0.2	0.1	0.3	0.1	0.2	0.1	0.1	Tr.
PLANT MATERIALS										
Diatoms	Na.[5]	Tr.	Na.	Tr.	Na.	Tr.	Na.	Tr.	Na.	Tr.
Filamentous algae	Na.	Tr.	Na.	Tr.	Na.	Tr.	Na.	Tr.	Na.	301.4
Detritus[6]	Na.	596.0	Na.	271.3	Na.	609.1	Na.	1,068.0	Na.	494.5
TOTALS										
Excluding plant materials	53.1	56.3	86.8	40.5	27.8	14.8	39.9	28.2	53.8	43.4
Including plant materials	Na.	652.3	Na.	311.8	Na.	623.9	Na.	1,096.0	Na.	537.9

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[1] Tr. = less than 0.05 individuals or mg/m^3.

[2] Including for present purposes: HEMIPTERA - Mesoveliidae and Microveliidae; TRICHOPTERA - Hydroptilidae; DIPTERA - Tipulidae, Culicidae, Dixidae, and Empididae; COLEOPTERA - Elmidae, Dytiscidae, Haliplidae, and Hydrophilidae; HYDRAZOA - Hydridae; and NEMATODA - Undetermined taxa.

[3] Including: PLECOPTERA - Capniidae; and TRICHOPTERA - Undetermined adults.

[4] Including for present purposes: COLLEMBOLA - Undetermined taxa and Sminthuridae; THYSANOPTERA - Thripidae; HEMIPTERA - Undetermined terrestrial taxa; HOMOPTERA - Aphididae and Undetermined taxa; COLEOPTERA - Staphylinidae; HYMENOPTERA - Chalcidoidea and Formicidae; MALLOPHAGA - Undetermined taxa; ARANEIDA - Undetermined taxa; and TARDIGRADA - Undetermined taxa.

[5] Na. = Not applicable.

[6] Leaf litter was not included.

Trichopteran larvae of the genera Hydropsyche and Cheumatopsyche (Hydropsychidae) were scarce early in the study, but became more important later as a major component of biomass in benthic samples (Table 2) and a relatively common taxon in drift (Table 3). Glossosomatid trichopterans followed a similar trend. High biomass estimates for trichopterans, especially the hydropsychids, typically resulted from presence of a few large individuals, rather than from a dense population.

A large number of other animals were recorded in benthos and drift samples (Table 1), some in small numbers or only occasionally, and others seasonally. Especially seasonal in abundance was the capniid plecopteran Capnia frisoni Baumann and Gaufin, which was present only in periods of cool weather, and turbellarians, that appeared in summer samples in benthos, but did not enter the drift (Tables 2 - 3).

Interrelationships of Benthos and Drift

Variance in samples from benthic communities is notoriously high (Needham and Usinger 1956, Elliott 1971), presumably as a result of heterogeneity of stream habitats joined with diversified life histories and behaviors of faunal constituents. Drift of certain organisms (i.e. baetid mayflies) has, however, been demonstrated to be consistent and predictable, and has been proposed as another measure of invertebrate populations in streams, possibly more sensitive than direct sampling of benthos (Waters 1965, 1972). Mixing action of turbulence tends to suppress affects of heterogeneity.

The relationship between drift and standing crop of benthos at a given place is only a general one, especially if habitats upstream vary

significantly from that at the point of sampling. Waters (1965) estimated, on the basis of blocking a stream, that organisms drifting at a given place originated no more than 50 to 60 m upstream. Comparisons of standing crops of benthos and drift at my station was justified by similarity of habitat throughout the study reach and by lack of statistical differences in numbers and biomass at my station and another site immediately above (see Bruns 1977). In addition, sampling of drift and benthos were always taken about midway in a 60-m-long, uniform riffle that comprised my study reach (Fig. 2), so that comparative integrity of data was maintained.

In Aravaipa Creek, 36 items were recorded from samples of benthos. Twenty-six (72.2%) of these were nymphs, larvae, pupae, and non-emerging adults of aquatic insects, 7 (19.4% were other aquatic invertebrates, and 3 (8.3%) were non-animal categories (algae, diatoms, and detritus). Drift sampling caught items of 66 taxonomic categories (Table 1). Of these, 27 (49.1%) were aquatic insects (nymphs, larvae, pupae, and non-emerging adults), 5 (9.1%) were emergent adults of aquatic insects, 7 (12.7%) were other aquatic invertebrates, and 13 (23.6%) were invertebrates of terrestrial origin. Three (5.5%) were the non-animal components defined above.

Invertebrates common to both drift and benthos included all important categories discussed before (Tables 1 - 3). Slightly more than 65% of drift (excluding non-animal components) was derived from the benthos, and this rose to 75% when emerged adults of aquatic insects were included. Three of four items in drift of Aravaipa Creek were therefore autochthonous to the system. Of 32 benthic taxa recorded (again excluding the

non-animal items), 23 (71.4%) drifted. Groups of benthic animals absent from drift samples included Libellulidae (dragonflies), Tabanidae (horseflies), Muscidae (houseflies), Rhagoveliidae (water striders), Helicopsychidae and Limnophilidae (caddisflies), Corydalidae (hellgrammites), Hirudinea (leeches), and turbellarians (flatworms). Absence of all but the last from drift may generally be attributed to their rarity in the stream. Turbellarians appear to resist drifting in Aravaipa Creek.

Of organisms drifting, only baetid and tricorythid mayflies and chironomid dipteran larvae and pupae were present in all samples on all sampling dates. Numbers of those animals per cubic meter of water correlated roughly with numerical standing crops estimated by benthic sampling in the same periods, but no such relationships exist between their weights in drift and those in benthos (Fig. 4a - c; $r^2 < 0.5$). Similar comparisons of drift and benthic standing crops at the community level (Fig. 4d) show no relationships.

Foods of Fishes

Nymphal mayflies comprised 57% or more of stomach contents of 5 of the 6 fish species quantitatively analysed for this report (Fig. 5). Only the herbivorous Pantosteus clarki contained few ephemeropterans. Dipteran larvae were most common in stomachs of the more bottom dwelling species, Rhinichthys osculus, Tiaroga cobitis, and Catostomus insignis. Trichopteran larvae were less than 10% of total food volumes in all but T. cobitis, but were present in significant amounts in all but P. clarki stomachs. Plecopteran nymphs also were eaten in small portions by all species, but the mountain-sucker contained only traces of that

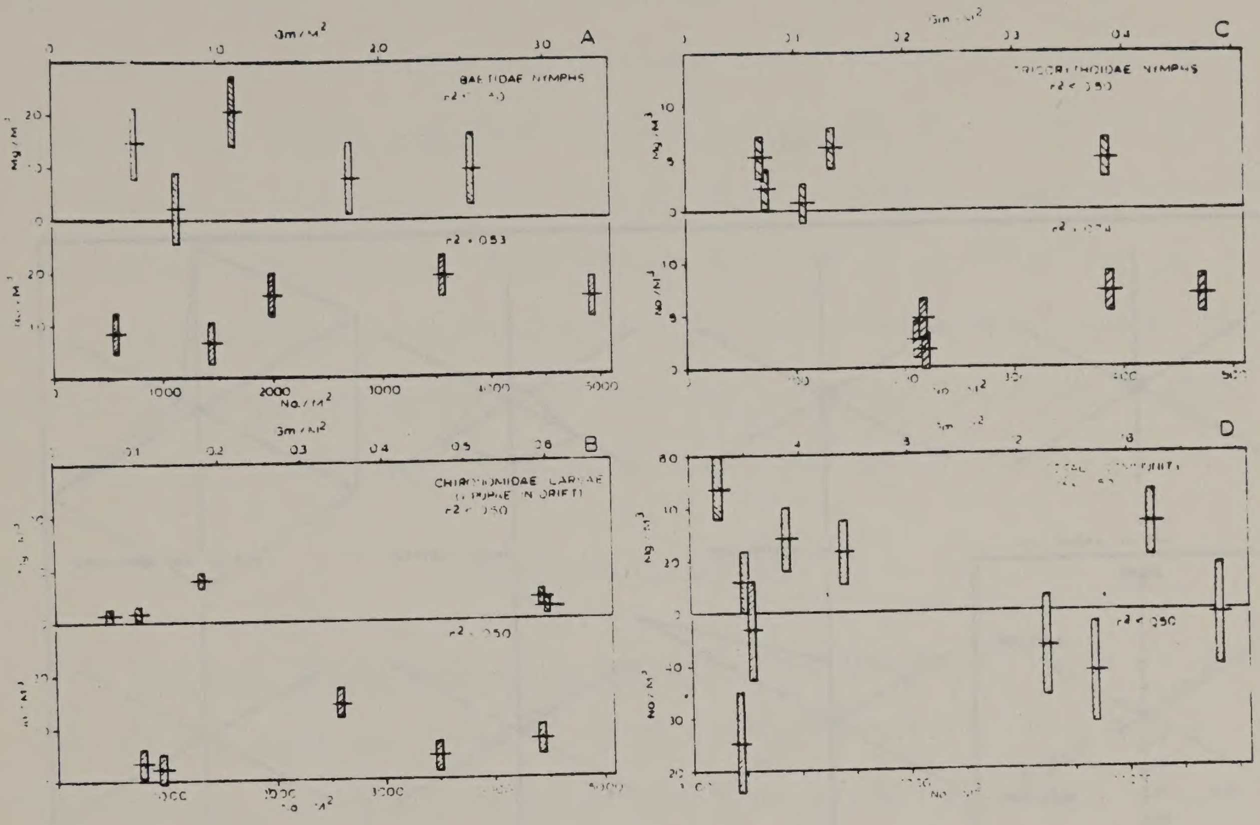

Fig. 4. Weights and numbers per cubic meter compared with standing crops and biomass per square meter of invertebrates in Aravaipa Creek, Arizona, 1975-76. Correlation coefficients (r^2) were computed following Woolf (1968). They are presented here, and in text, to demonstrate relationships rather than to test for significance of correlation. Vertical bars represent one standard error on either side of the mean (horizontal line).

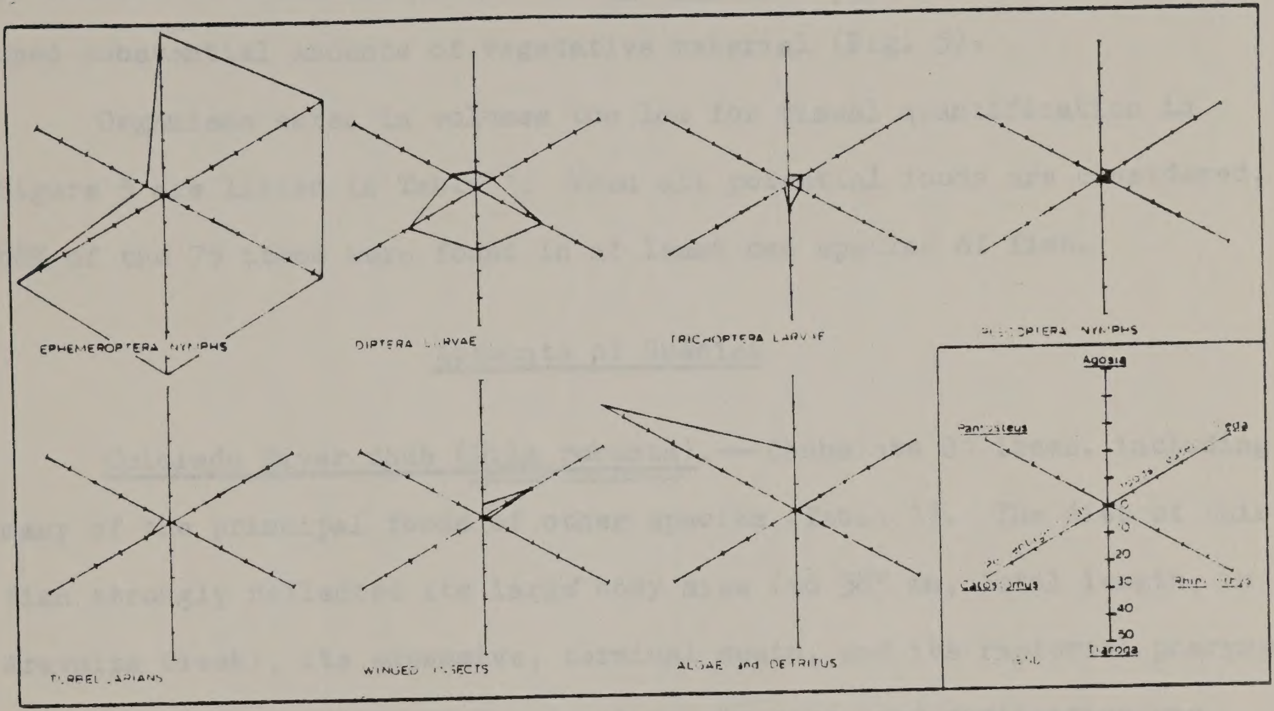

Fig. 5. Annual averages of relative percentages of major food items eaten by six species of fishes in Aravaipa Creek, Arizona, 1975 - 76.

taxon (Fig. 5). Turbellarians were heavily preyed upon by C. insignis and P. clarki when they were present in summer, but other fishes did not eat them. Winged insects (including both emerged aquatic forms and scarcer terrestrial kinds) were consumed in more than trace amounts by Meda fulgida, Agosia chrysogaster, and R. osculus, in decreasing order of volumes in stomachs. Other than P. clarki, only A. chrysogaster consumed substantial amounts of vegetative material (Fig. 5).

Organisms eaten in volumes too low for visual quantification in Figure 5 are listed in Table 1. When all potential foods are considered, 88% of the 75 items were found in at least one species of fish.

Accounts of Species

Colorado River chub (Gila robusta).—Chubs ate 21 items, including many of the principal foods of other species (Table 1). The diet of this fish strongly reflected its large body size (to 385 mm, total length, in Aravaipa Creek), its expansive, terminal mouth, and its raptorial pharyngeal teeth. Many of its foods were large in size, and mastication was apparent and extensive (James Burton, personal communication). Chubs are secretive animals, inhabiting deeper waters near cover, yet the occurrence of terrestrial organisms such as an iguanid lizard and ants, along with a variety of benthic inhabitants (e.g. Odonata larvae), other fishes, and belostomatid hemipterans, indicates an active feeding range from surface to bottom. The uniqueness of this diet is exemplified by only 38.1% of the food items recorded also being consumed by the other fish species (Table 4). Six (28.6%) of the items found in G. robusta stomachs did not appear in any other fish species.

Table 4. Numbers and percentages of total food items eaten by each species of fish in Aravaipa Creek, Arizona, 1975-76, that also were eaten by another species. To determine what percentage of a species' diet also was consumed by another, read vertically. To determine what percentage a given fish consumed of another species' diet, read horizontally. Total numbers of food items eaten by each kind of fish are in parentheses.

Species	A)		B)		C)		D)		E)		F)		G)		Means	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
A) *G. robusta* (21)	---	---	5	12.8	9	25.0	8	34.8	6	54.5	11	28.9	9	52.9	8.0	38.1
B) *A. chrysogaster* (39)	5	23.8	---	---	29	80.6	19	82.6	10	90.9	26	68.4	14	82.4	17.2	44.1
C) *M. fulgida* (36)	9	42.9	29	74.4	---	---	19	82.6	10	90.9	21	55.3	13	76.5	16.8	46.8
D) *R. osculus* (23)	8	38.1	19	48.7	19	52.8	---	000	10	90.9	18	47.4	15	88.2	14.8	64.3
E) *T. cobitis* (11)	6	28.6	10	25.6	10	27.8	10	43.5	---	---	10	26.3	9	52.9	9.2	83.6
F) *C. insignis* (38)	11	52.3	26	66.7	21	58.3	18	78.3	10	90.9	---	---	15	88.2	16.8	44.3
G) *P. clarki* (17)	9	42.9	14	35.9	13	36.1	15	65.2	9	81.8	15	39.5	---	---	12.5	73.5

Longfin dace (Agosia chrysogaster).—Thirty-nine kinds of foods were tallied from stomachs of *A. chrysogaster* (Table 1), the greatest diversity recoreed for any fish species from Aravaipa Creek. The percentages of foods eaten by longfin dace that also were consumed by other species (average 44.1%; Table 4) is, however, somewhat misleading since separate algal and diatom taxa were not compiled. Had diversity of plants been considered, indicated overlaps between fishes other than *P. clarki* and *A. chrysogaster* (ranging from 12.8% for *G. robusta* and longfin dace to 74.4% for spikedace and that species) would have been far less, and that between longfin dace and Gila mountain-sucker (35.9%) far greater. Omnivory causes the longfin dace to be special within the system; with far greater latitude for action within the trophic structure.

Filamentous algae (identified only to genus) made up 9.8 to 53% of total food volumes in *A. chrysogaster* from Aravaipa Creek (Table 5). *Cladophora*, the dominant alga in the channel (Bruns 1977), was rarely present in stomachs. Unattached green algae (*Mougiotia* and *Spirogyra*) were abundant, and occasionally, bluegreen filamentous forms such as *Oscillatoria* were present. These plants are characteristic of stream margins and quiet areas near beds of higher vegetation, and their presence in stomachs reflects grazing by longfin dace in such areas.

Of ephemeropteran nymphs eaten by *A. chrysogaster*, the ubiquitous baetids predominated in 4 of 5 sampling periods (ranging from 23 to 61.4% of total foods consumed). The relationship between drift biomass of baetids and occurrence in longfin dace stomachs seems quite strong ($r^2 =$ 0.81). There is no obvious relationship between benthic standing crop and stomach contents ($r^2 =$ 0.5). Tricorythid mayflies were preyed upon

Table 5. Food habits of longfin dace, Agosia chrysogaster, from Aravaipa Creek, Arizona, 1975-76. Organisms not occurring at more than trace (Tr. = < 1.0%) amounts in any sampling period are not included; numbers of fish are in parentheses.

Food items	Percentages Total Stomach Volumes					Percentages Total Food Volumes				
	Jan (70)	Apr (32)	Jul (40)	Oct (40)	Jan (41)	Jan	Apr	Jul	Oct	Jan
EPHEMEROPTERA NYMPHS	9.7	17.8	4.7	6.2	24.9	45.1	60.7	47.0	68.9	66.8
Baetidae	8.6	7.1	2.3	3.9	22.9	40.0	24.2	23.0	43.3	61.4
Tricorythidae	---	10.7	1.0	2.3	2.0	---	36.5	10.0	25.6	5.4
Leptophlebiidae	Tr.	---	1.4	Tr.	---	Tr.	---	14.0	Tr.	---
Heptageniidae	1.1	---	---	---	Tr.	5.1	---	---	---	Tr.
PLECOPTERA NYMPHS (Capniidae)	2.2	---	---	---	1.1	10.2	---	---	---	3.0
TRICHOPTERA LARVAE (Hydropsychidae)	---	Tr.	Tr.	Tr.	3.5	----	Tr.	Tr.	Tr.	9.4
DIPTERA LARVAE AND PUPAE	6.1	1.3	Tr.	Tr.	Tr.	28.4	4.4	Tr.	Tr.	Tr.
Chironomidae	3.7	Tr.	Tr.	Tr.	Tr.	17.3	Tr.	Tr.	Tr.	Tr.
Simuliidae	2.4	1.3	Tr.	Tr.	Tr.	11.2	4.4	Tr.	Tr.	Tr.
WINGED INSECTS	1.4	3.7	Tr.	Tr.	Tr.	6.5	12.6	Tr.	Tr.	Tr.
Ephemeroptera	---	3.7	---	Tr.	Tr.	6.5	12.6	Tr.	Tr.	Tr.
Chironomidae	1.4	Tr.	Tr.	Tr.	Tr.	6.5	Tr.	Tr.	Tr.	Tr.
ALGAE (Filamentous algae)	2.1	6.5	5.3	2.8	7.8	9.8	22.2	53.0	31.1	20.8

in all but the January 1975 period, occupied more volume in stomachs in April than did baetids (36.5 *versus* 24.2%), and were eaten in substantially smaller amounts than baetids in the periods July 1975 through January 1976. Since tricorythids rarely achieved half the numbers or biomass values of baetids in drift or benthos samples (Tables 2 - 3), some special association with longfin dace was indicated. The three species of tricorythids recorded by Bruns (1977) from Aravaipa Creek (*Tricorythodes minutus* Allen, *T. dimorphus* Allen, and *T. condylus* Allen) were most abundant in sand-bottomed areas. Longfin dace frequent almost all habitats in the stream, but also tend to be most abundant in open, sandy areas, with moderate current, in water less than 10 cm deep (especially in periods of low light intensity; Minckley and Barber 1971).

Leptophlebiid and heptageniid mayflies made up only a small proportion of the diet of longfin dace. The former was present as 14% of total food volume in July, and was absent or occurred in trace amounts in other months (Table 5) despite its consistent presence in both benthos and drift (Tables 2 - 3). The common leptophlebiid (*Choroterpes inornatus* Eaton) and the heptageniid *Rithrogena* (species undetermined) both are strongly rheophilic and associated with cobble bottomed rapids in Aravaipa Creek (Bruns 1977), a habitat rarely occupied by longfin dace. Heptageniids were, however, present in *A. chrysogaster* stomachs in their period of occurrence in the creek (January of both years).

Plecopteran nymphs were eaten during their period of winter occurrance, as with Heptageniidae. Appearance of hydropsychid trichopterans in stomachs corresponded well with their spectacular increase in biomass in benthos in January 1976 (Table 2), and with an increase in drift during

that period (although far less impressive; Table 3). The increase in volumes eaten resulted from a few, relatively large individuals, rather than an increase in numbers (as also occurred in benthic samples).

Dipteran larvae made up a substantial percentage of total food volumes in A. chrysogaster only in January 1975, the same period in which each of the represented families (Chironomidae and Simuliidae) were most common in drift. A gradual decline in drift of dipterans throughout the study was paralleled by a continuing drop in volumes of these animals in the diet. Occurrences of chironomid and similiid dipterans in benthic samples were consistent, but variations in indicated standing crops do not correspond to those in stomachs. Chironomids are a diversified group, generally distributed within the stream. The small occurrences of the highly rheophilic Simuliidae, however, tend to substantiate a general lack of feeding by longfin dace on swift, turbulent riffles.

Presence of winged insects in stomachs of A. chrysogaster, especially trace amounts of terrestrial homopterans and coleopterans (Table 1), indicates some feeding at the surface. However, correspondence of frequencies of ephemeropteran and chironomid adults in drift and in stomachs is far less than perfect. Both items drifted throughout the year, and chironomids were consistently taken by A. chrysogaster, while mayflies were not. Perhaps the relatively large size of adult mayflies causes the small-mouthed longfin dace to select against them. The dace ate more mayfly adults in April, while they drifted most in January of both years, and more chironomid adults in January 1975 than in January 1976, wherein they were equally abundant in the drift.

Spikedace (*Meda fulgida*).—Patterns of use of nymphal ephemeropterans by *M. fulgida* in Aravaipa Creek closely followed those just described for *A. chrysogaster* (Table 6). Spikedace occupy deep pools, or areas of deeper water below riffles in most streams (Miller and Hubbs 1960). In Aravaipa Creek, where pools are essentially absent, the fish is typically in mid- to surface water of the deeper parts of the channel, or in runs of moderately swift current. Spikedace are relatively small (< 75 mm, total length), active, highly mobile fish, moving continuously and visually inspecting almost all drifting materials at the surface and within the water column. Gustatory inspection also is commonly practiced, with items being taken into the large, terminal mouth, moved about, then swallowed or rejected. The 36 food items recovered from stomachs illustrate its versatility. A high percentage (22%) of terrestrial organisms, few of which were eaten by other species (Table 1), produced a diet qualitatively as unique as that of *Gila robusta* (Table 4).

Total volumes of baetid nymphs in stomachs and biomass of drift did not correlate as highly for *M. fulgida* ($r^2 = 0.68$) as they did for *A. chrysogaster*. Baetids in benthos samples were not related to total volumes in spikedace stomachs ($r^2 = < 0.5$). Tricorythid nymphs in the benthos were correlated with total volumes in spikedace ($r^2 = 0.91$), but no such relationship was apparent between stomach volumes and drift ($r^2 < 0.5$). Again, open, sandy-bottomed areas of the channel occupied by both tricorythid nymphs and spikedace presumably enhanced their interrelationship. Leptophlebiid, heptageniid, and ephemerellid nymphs made up a minor part of the overall diet. The first of these families did, however, contribute 13% in a single sampling period (July).

Table 6. Food habits of spikedace, *Meda fulgida*, from Aravaipa Creek, Arizona, 1975-76. Organisms not occurring at more than trace (Tr. = < 1.0%) amounts in any sampling period are not included; numbers of fish are in parentheses.

Food items	Percentages Total Stomach Volumes					Percentages Total Food Volumes				
	Jan (28)	Apr (22)	Jul (33)	Oct (37)	Jan (20)	Jan	Apr	Jul	Oct	Jan
EPHEMEROPTERA NYMPHS	28.2	50.7	19.2	20.4	41.8	52.2	78.0	53.0	83.0	69.6
Baetidae	24.4	36.6	9.6	17.7	40.5	45.3	56.3	26.5	72.0	67.5
Tricorythidae	2.0	12.4	4.9	2.7	1.3	3.6	19.1	13.5	11.0	2.1
Heptageniidae	1.8	---	---	---	---	3.3	----	---	---	---
Leptophlebiidae	Tr.	Tr.	4.7	Tr.	---	Tr.	Tr.	13.0	Tr.	---
Ephemerellidae	---	1.7	---	---	---	---	2.6	---	---	---
PLECOPTERA NYMPHS (Capniidae)	7.0	---	---	Tr.	1.5	12.9	---	---	Tr.	2.5
TRICHOPTERA LARVAE (Hydropsychidae)	---	1.7	2.9	Tr.	7.3	---	2.6	8.0	Tr.	12.1
DIPTERA LARVAE AND PUPAE	7.4	2.8	2.0	2.8	Tr.	13.8	4.4	5.5	11.5	Tr.
Chironomidae	5.0	1.4	2.0	Tr.	Tr.	9.3	2.2	5.5	Tr.	Tr.
Simuliidae	2.4	1.4	Tr.	2.8	Tr.	4.5	2.2	Tr.	11.5	Tr.
WINGED INSECTS	11.2	9.8	12.1	1.4	9.5	20.5	15.1	33.5	5.5	15.8
Ephemeroptera	7.0	9.8	Tr.	1.4	6.0	12.9	15.1	Tr.	5.5	10.0
Chironomidae	4.2	Tr.	1.5	Tr.	Tr.	7.6	Tr.	4.2	Tr.	Tr.
Trichoptera	---	---	10.6	Tr.	3.5	---	---	29.3	Tr.	5.8

Plecopteran nymphs were used by spikedace when present, being most frequently eaten in January 1975 when also most common in drift. Hydropsychid trichopteran larvae were in stomachs in all but the first sampling period, and were major contributors to the total food volume in July 1975 and January 1976. These organisms made up a disproportionate percentage in July (8%) as compared to their low relative abundances in benthos and drift (2.7 and 1.5%, respectively), perhaps indicating selection by the fish.

Spikedace fed more heavily on winged insects than did any other fish species in Aravaipa Creek, with an average total volume throughout the study of more than 20% (Fig. 5). Mayfly adults were generally most abundant, paralleled or closely followed by chironomid adults. Opportunism seemed the rule in M. fulgida, and active feeding on emerging trichopterans was apparent in July. Trichopteran adults made up a major part of the diet in that sampling period, 29.3% of total volumes recorded (Table 6).

Speckled dace (*Rhinichthys osculus*).—This dace has a strong proclivity for riffles, within a broader range of habitat selection (Minckley 1973). Its diet in Aravaipa Creek, which consisted largely of rheophilic insects (Table 7), reflected the habitat. Food habits of speckled dace overlap widely with those of A. chrysogaster and M. fulgida, however, with more than 80% of its foods also eaten by the other two species (Table 4).

Ephemeropteran nymphs made up more than 70% of the total food volume of R. osculus in all but the first sampling period. Tricorythid and leptophlebiid nymphs, species of open, sand-bottomed channels and of

Table 7. Food habits of speckled dace, Rhinichthys osculus, from Aravaipa Creek, Arizona, 1975-76. Organisms not occurring at more than trace (Tr. = $<$ 1.0%) amounts in any sampling period are not included; numbers of fish are in parentheses.

Food items	Percentages Total Stomach Volumes					Percentages Total Food Volumes				
	Jan (12)	Apr (6)	Jul (38)	Oct (36)	Jan (34)	Jan	Apr	Jul	Oct	Jan
EPHEMEROPTERA NYMPHS	17.1	27.5	23.3	17.7	16.8	34.7	76.8	76.2	79.0	72.9
Baetidae	15.0	8.3	10.3	16.5	16.8	30.5	23.3	33.6	73.7	71.1
Tricorythidae	---	10.0	5.8	1.2	Tr.	---	27.9	18.9	5.3	1.8
Heptageniidae	2.1	---	---	---	Tr.	4.2	---	---	---	Tr.
Leptophlebiidae	---	6.7	7.2	---	---	---	18.6	23.7	---	---
Ephemerellidae	---	2.5	---	---	---	---	7.0	---	---	---
PLECOPTERA NYMPHS (Capniidae)	6.3	---	---	---	Tr.	12.7	---	---	---	Tr.
TRICHOPTERA LARVAE (Hydropsychidae)	---	---	Tr.	1.0	6.2	---	---	Tr.	4.6	26.1
DIPTERA LARVAE AND PUPAE	25.8	8.3	4.7	3.7	Tr.	52.6	23.3	15.0	16.3	Tr.
Chironomidae	5.8	5.8	1.9	1.8	Tr.	11.9	16.3	6.0	7.9	Tr.
Simuliidae	20.0	2.5	2.8	1.9	Tr.	40.7	7.0	9.0	8.5	Tr.
WINGED INSECTS (Trichoptera)	---	---	2.6	---	Tr.	---	---	8.6	---	1.1

cobble-bottomed rapids, respectively, had a combined volume exceeding that of baetids in April and July (Table 7). This resembled the pattern for A. chrysogaster in the same periods (Table 5), but was distinct from that for M. fulgida (Table 6), where baetids dominated stomach contents.

Plecopteran nymphs were preyed upon when present in winter, and in greatest quantities in January 1975. Hydropsychid larvae increased in importance from July 1975, to become a major component of the total food consumed in January 1976. This followed the pattern of increase in caddisflies in benthos and drift (Tables 2 - 3).

Dipteran larvae and pupae were more heavily used by the bottom feeding speckled dace than by either longfin dace or spikedace. High levels of predation by R. osculus on dipterans at the onset of the study gradually declined, however, parallel to the pattern of indicated relative availability. Rates of feeding upon dipteran larvae were, however, unrelated to densities in benthic samples. There was no correlation between stomach contents and either drift or benthos ($r^2 < 0.5$). Simuliidae was heavily used, further implying extensive feeding by speckled dace in riffle habitats.

Trichopteran adults were taken by R. osculus in July and January 1976. Since speckled dace was rarely observed near the surface, it is likely that these animals were caught during emergence from benthic puparia. Only one of 23 food items recorded for speckled dace was of terrestrial origin (Table 1), further supporting a lack of surface feeding activity by the species.

Loach minnow (*Tiaroga cobitis*).—This species was relatively rare in Aravaipa Creek during the period of study. A total of 47 individuals

was examined, with a range of numbers per sampling period of 3 to 14 individuals (Table 8). This diminutive minnow is current loving and benthic in habit, an ecological equivalent of darters (Percidae, Etheostominae) of eastern North America, living exclusively on riffles less than 15 cm deep (Minckley 1965, 1973).

This restriction in habitat manifested itself in an equally limited diet in Aravaipa Creek. Only 11 items were tallied from stomachs of T. cobitis, and of these only two are sometimes associated with non-riffle habitats (tricorythid nymphs and tabanid dipteran larvae, the latter occurring as only a trace; Table 1). Ubiquity of baetid mayflies and chironomid larvae reduce their value in interpretation of feeding habitat of the loach minnow, but both were common on riffles. Cobble-inhabiting, swift-water forms such as heptageniid and leptophlebiid nymphs reflect occupation of riffles by the fish, as do the large percentages of simuliid dipteran larvae eaten in early periods of the study (Table 8). Of other fishes in the stream, only Gila robusta used less than 80% of the food items depended upon by T. cobitis, and most species ate more than 90% (Table 4).

Ephemeropteran nymphs made up most of the diet of T. cobitis during three sampling periods, baetids being most important in each instance. Tricorythid numphs were abundant in stomachs only in April, leptophlebiids were taken mostly in July 1975 and January 1976, and ephemerellids were eaten in moderate quantities when most abundant in April (Table 8). Plecopteran nymphs composed a minor percentage of total volumes in January 1975. Active selection for trichopteran larvae by loach minnows is indicated in July. Neither of the families of caddisflies that were eaten

Table 8. Food habits of loach minnow, Tiaroga cobitis, from Aravaipa Creek, Arizona, 1975-76. Organisms not occurring at more than trace (Tr. = < 1.0%) amounts in any sampling period are not included; numbers of fish are in parentheses.

Food items	Percentages Total Stomach Volumes					Percentages Total Food Volumes				
	Jan (12)	Apr (3)	Jul (14)	Oct (12)	Jan (6)	Jan	Apr	Jul	Oct	Jan
EPHEMEROPTERA NYMPHS	30.0	35.0	9.8	16.5	55.8	43.7	77.7	34.6	61.6	90.6
Baetidae	30.0	25.0	7.5	16.5	47.5	43.7	55.6	26.5	61.6	77.1
Tricorythidae	---	7.5	Tr.	Tr.	2.5	---	16.7	Tr.	Tr.	4.1
Leptophlebiidae	Tr.	---	2.3	Tr.	5.8	Tr.	---	8.1	Tr.	9.4
Ephemerellidae	---	2.5	---	---	---	---	5.5	---	---	---
PLECOPTERA NYMPHS (Capniidae)	1.4	---	---	---	---	2.0	---	---	---	---
TRICHOPTERA LARVAE	---	---	13.3	1.5	5.8	---	---	47.3	5.6	9.4
Hydropsychidae	---	---	8.0	1.5	5.8	---	---	28.2	5.6	9.4
Glossosomatidae	---	---	5.3	---	---	---	---	18.8	---	---
DIPTERAN LARVAE AND PUPAE	37.3	10.0	5.2	5.0	Tr.	54.3	22.2	18.3	18.1	Tr.
Chironomidae	6.8	2.5	Tr.	Tr.	Tr.	9.9	5.5	Tr.	Tr.	Tr.
Simuliidae	30.5	7.5	5.2	5.0	Tr.	44.4	16.7	18.3	18.7	Tr.
WINGED INSECTS (Trichoptera)	---	---	---	3.8	---	---	---	---	14.3	---

were abundant in drift or benthos at that time (Tables 2 - 3), yet hydropsychid larvae made up 28.2% of the total food volume, and glossosomatid larvae 18.8%. Neither group was present in stomachs in January and April 1975 (perhaps because of a small sample size in the latter month), and only hydropsychids persisted as food items in October 1975 and January 1976.

The gradual decline in percentages of dipteran larvae recorded for stomachs of other minnow species throughout the study was less pronounced in _T. cobitis_ because of its extensive cropping of simuliids in all but the last sampling period. Chironomid larvae were a relatively minor component of the overall diet of the loach minnow (Table 8).

Winged trichopterans appeared in stomachs in October, presumably having been captured upon emergence from puparia. Loach minnows cannot maintain position in midwater without violent swimming effort, due in part to a greatly reduced air bladder. Feeding from the surface or even midwater areas of turbulent riffles is therefore unlikely. It is interesting, however, that regression coeficients between stomach volumes of _T. cobitis_ and some components of drift were relatively high (_e.g._ for total ephemeropterans, $r^2 = 0.86$), and no such relationships were found between benthic biomass and stomach contents. The fish appears to directly sample benthic areas from which much of the drift is derived, and the gross estimation of benthic communities afforded by my sampling was far less adequate.

Gila coarse-scaled sucker (Catostomus insignis).—This large species exhibited a generalized, carnivorous diet in Aravaipa Creek. The fish is typically a pool dweller (Minckley 1973), living on the

bottom in areas of cover such as undercut banks, boulders, or logs and other debris along the channel. It will sometimes visit midwater, and despite the suctorial mouth, has been observed to take food items in that area. Although the diet of *C. insignis* was almost as diversified as that of *A. chrysogaster* (38 items, Table 1), the average overlap with other species in Aravaipa Creek was only 44.3 (range 26.3 to 68.4%; Table 4). Most food items unique to the sucker were small, bottom-dwelling forms such as Acarina and microcrustaceans (Table 1).

Baetid ephemeropteran nymphs were important foods of *C. insignis* through much of the study period, but tricorythid nymphs became progressively more so, and were the dominant mayfly in stomachs in January 1976 (Table 9). Abundance of tricorythids in benthos and drift did not follow that same pattern (Tables 2 - 3). Ephemerellid nymphs were abundant in stomachs only in April, and plecopteran nymphs contributed significantly to the diet only in January 1975. The only trichopteran larvae found in substantial numbers were glossosomatids, present in the greatest volumes in January 1976, at the peak of their density in the benthos (Table 2).

Dipteran larvae made up the largest portion of stomach contents in January 1975, and tended to decrease in relative volume with time (Table 9). Chironomids remained important in stomachs of *C. insignis* throughout the study, fluctuating erratically with respect to availability indicated by benthic and drifting densities. Simuliid larvae were significant only in the first two sampling periods.

Summer-active turbellarians were heavily preyed upon by Gila coarse-scaled suckers, with some individual fish containing them exclusively in July.

Table 9. Food habits of Gila coarse-scaled sucker, Catostomus insignis, from Aravaipa Creek, Arizona, 1975-76. Organisms not occurring at more than trace (Tr. = $<$ 1.0%) amounts in any sampling period are not included; numbers of fish are in parentheses.

Food items	Percentages Total Stomach Contents					Percentages Total Food Volumes				
	Jan (7)	Apr (3)	Jul (17)	Oct (17)	Jan (18)	Jan	Apr	Jul	Oct	Jan
EPHEMEROPTERA NYMPHS	17.6	21.7	7.8	17.1	18.9	37.4	76.4	33.1	84.7	80.9
Baetidae	16.3	16.7	5.3	12.4	9.2	34.7	58.8	22.5	61.4	39.3
Tricorythidae	1.3	1.7	2.5	4.7	9.7	2.7	6.0	10.6	23.3	41.6
Ephemerellidae	---	3.3	---	---	---	---	11.6	---	---	---
PLECOPTERA NYMPHS (Capniidae)	3.1	---	---	Tr.	Tr.	6.7	---	---	Tr.	Tr.
TRICHOPTERA LARVAE (Glossosomatidae)	---	Tr.	Tr.	Tr.	1.7	---	Tr.	Tr.	Tr.	7.2
DIPTERA LARVAE AND PUPAE	26.3	5.0	4.2	1.8	2.8	56.0	17.6	17.9	8.9	11.9
Chironomidae	21.3	1.7	4.2	1.8	2.8	45.3	6.0	17.9	8.9	11.9
Simuliidae	5.0	3.3	Tr.	Tr.	Tr.	10.7	11.6	Tr.	Tr.	Tr.
TURBELLARIA	Tr.	1.7	11.6	1.3	Tr.	Tr.	6.0	49.0	6.4	Tr.

Of foods eaten by *C. insignis*, ephemerellids, simuliids, and glossosomatids are characteristic of swift-water habitats. Their sporadic and relatively low occurrences in stomachs may be explained by drift of the animals into pools, where consumed, or by infrequent visits of individual suckers to riffle areas. Nine of the additional 28 invertebrate taxa that occurred in stomachs of *C. insignis*, but were too rare to quantify (Table 1) also were characteristic of swifter areas. Fifteen taxa were typical of stream margins or pool-like habitats, and four were winged adults of aquatic insects or were derived from terrestrial sources. Diversity in the pool-inhabiting forms was especially impressive, with 7 families of dipteran larvae being represented along with all 3 groups of microcrustaceans, plus oligochaetes and nematodes.

As with *T. cobitis*, regression coefficients between some stomach contents of *C. insignis* and drift data were interestingly high, while those with benthic densities were low. Drifting ephemeropteran nymphs versus stomach volumes in the same periods gave $r^2 = 0.80$, and total dipteran larvae in the drift against stomach volumes was $r^2 = 0.92$. The only benthic value to exceed $r^2 =< 0.5$ was total ephemeropteran nymphs versus total mayflies in the stomachs ($r^2 = 0.58$).

Gila mountain-sucker (Pantosteus clarki).— This species is associated with more turbulent waters of the mainstream of Aravaipa Creek, moving into riffles and rapids from protected places near boulders, then returning. Larger adults frequent strongly-flowing, deeper waters near undercut banks and other obstructions, often syntopic with *C. insignis*.

Although dipteran larvae were a common component of the diet of mountain-suckers in January and April 1975, as were turbellarians in

Table 10. Food habits of Gila mountain-sucker, Pantosteus clarki, from Aravaipa Creek, Arizona, 1975 - 76. Organisms not occurring at more than trace (Tr. = < 1.0%) amounts in any sampling period are not included; numbers of fish are in parentheses.

Food items	Percentages Total Stomach Volumes					Percentages Total Food Volumes				
	Jan (41)	Apr (22)	Jul (19)	Oct (21)	Jan (22)	Jan	Apr	Jul	Oct	Jan
EPHEMEROPTERA NYMPHS (Baetidae)	Tr.	Tr.	Tr.	Tr.	4.8	Tr.	Tr.	Tr.	Tr.	29.1
DIPTERA LARVAE AND PUPAE	4.9	2.1	Tr	Tr.	Tr.	19.2	21.5	Tr.	Tr.	Tr.
Chironomidae	3.8	2.1	Tr.	Tr.	Tr.	14.9	21.5	Tr.	Tr.	Tr.
Simuliidae	1.1	Tr.	Tr.	Tr.	Tr.	4.3	TTr.	Tr.	Tr.	Tr.
TURBELLARIA	---	---	1.8	---	---	---	---	22.5	---	---
ALGAE	20.6	7.6	6.2	3.8	11.6	80.8	78.5	77.6	95.6	70.9
Filamentous algae	9.3	4.6	2.9	Tr.	9.1	36.5	47.6	36.3	5.9	55.6
Diatoms	11.3	3.0	3.3	3.8	2.5	44.3	30.9	41.3	89.7	15.3

July 1975, and baetid nymphs in January 1976, filamentous green algae and diatoms made up the major portion of total foods of P. clarki throughout the study (Table 10). Animal foods may well have been ingested incidental to plants. However, the high percentages of some groups on specific sampling dates (e.g. turbellarians in July) indicate some degree of facultative utilization.

The largest standing crops of filamentous algae in Aravaipa Creek were present in April 1975 and January 1976, and they were lowest in summer and autumn, largely due to scour by flooding from summer rains (Bruns and Minckley ms; Table 2). The lowest percentages of total food volumes occupied by filamentous algae in P. clarki stomachs were in the same two periods (Table 10). Although the dominant filamentous alga in the channel was Cladophora, only small quantities of that taxon were present in the fish. Genera of algae fed upon included those eaten by A. chrysogaster (Mougeotia and Spirogyra) in trace quantities, and scarce Rhizoclonium, plus abundant Oedogonium. The first three algae are generally along shorelines of Aravaipa Creek and the last in the channel as an abundant epiphyte of Cladophora

Diatoms also were adversely affected by spates, but recovered far more rapidly than large, attached algae, and rather consistent densities were maintained, especially in winter (Bruns 1977, Bruns and Minckley ms). When Cladophora choked the channel of the creek, P. clarki was observed mouthing fronds of the alga, and obviously removing attached materials with lateral movements of the head and sucking action of the mouth. Stomachs contained great amounts of diatoms and Oedogonium at that time, and fragments of Cladophora also had been ingested. After washout, the

mountain-sucker scraped epilithic diatom films from stones with the cartilagenous sheaths that invest its upper and lower jaws (in October; Table 10).

DISCUSSION

Fishes in Aravaipa Creek obviously present three general trophic patterns. The Gila mountain-sucker is the only herbivore, the longfin dace is at least a facultative omnivore, and the remaining five species are carnivorous. A single order of insects, the Ephemeroptera, bears the brunt of predation by most fish species (Fig. 5).

Mayfly nymphs averaged more than 60% of the total diets by volume in four carnivorous fishes for which quantitative data were compiled, and were also eaten by the Colorado River chub (Table 1), and by longfin dace (Table 5). Baetid mayfly nymphs were cropped more extensively than any other group (Tables 5- 9). were the most ubiquitous, and had greater biomass than other invertebrates (Tables 2- 3). Occurrences of other families of mayflies in stomachs appeared to reflect differing habitat preferences of predators and of the prey, and seasonality of life history phenomena of the latter. On a relative basis, mayfly nymphs were remarkably uniform in benthic biomass throughout the study, being reduced in importance by increases in hydropsychid trichopterans only in the last two sampling periods (Fig. 6). Relative importance of mayfly nymphs by weight remained uniform in drift samples.

Absolute values for benthos and drift, however, varied significantly from period to period (Fig. 7). Total drift was lowest in July, and the benthic biomass had declined at that time from the previous sampling period.

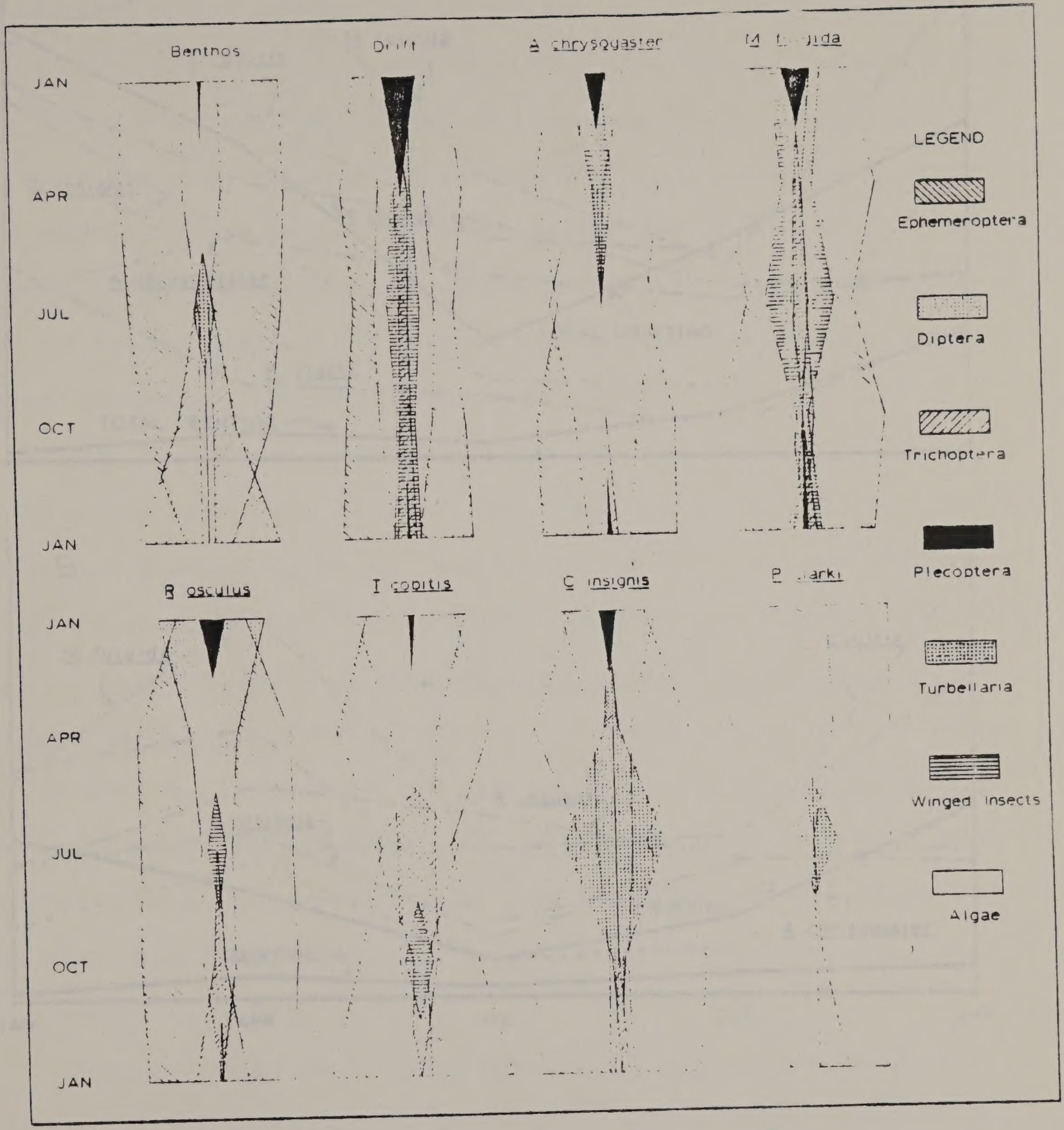

Fig. 6. Relative abundance (by weight) of major invertebrate taxa in benthos and drift, and of invertebrate taxa and algae in stomachs (by volume) of fishes from Aravaipa Creek, Arizona, 1975 - 76.

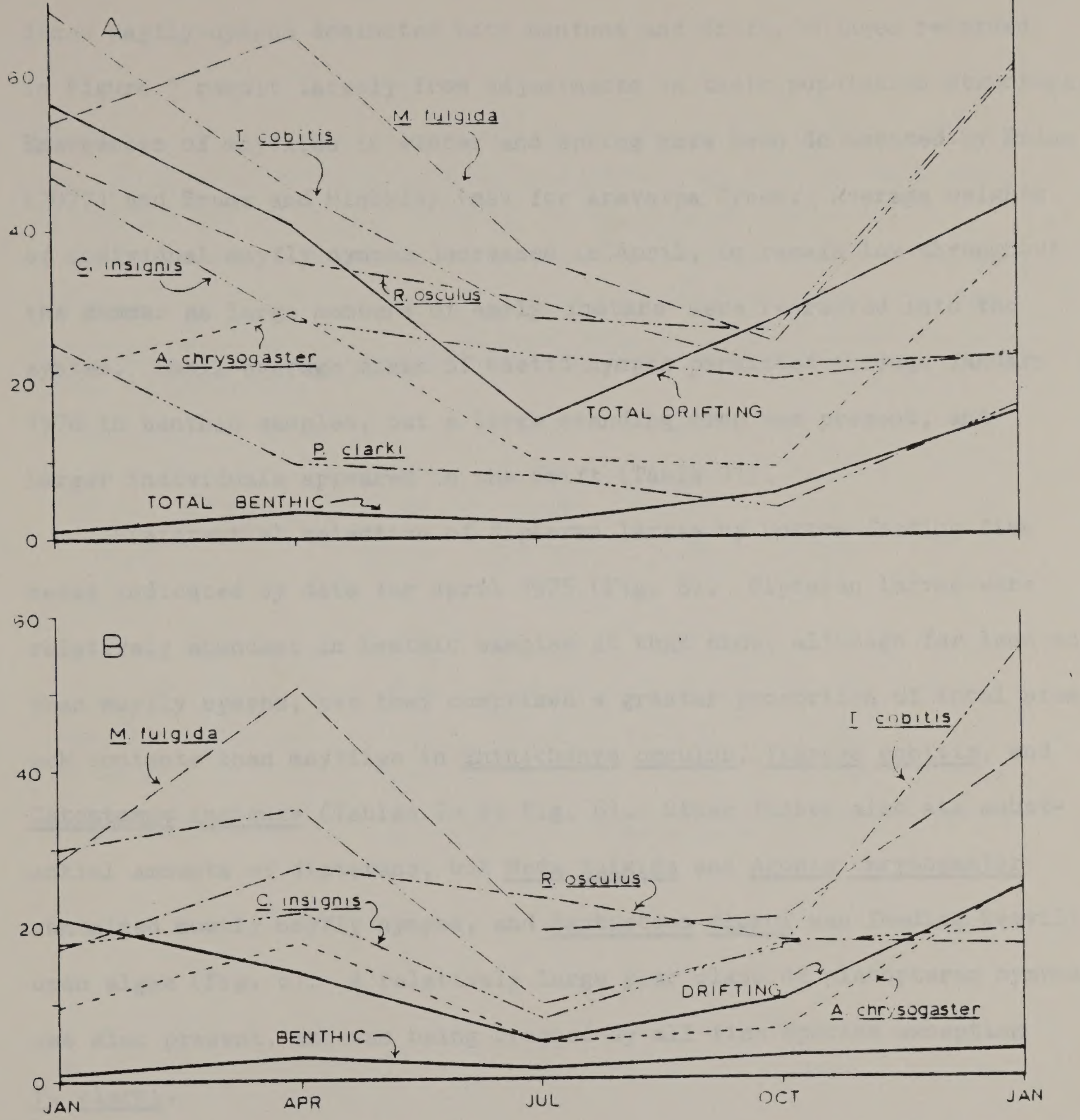

Fig. 7. Total weights of drift (mg/m^3), benthos (g/m^2), and percentages of total stomach volumes in six fish species for all invertebrate groups (A) and for ephemeropteran nymphs (B) from Aravaipa Creek, Arizona, 1975-76.

Since mayfly nymphs dominated both benthos and drift, changes recorded in Figure 7 result largely from adjustments in their population structure. Emergences of mayflies in winter and spring have been documented by Bruns (1977) and Bruns and Minckley (ms) for Aravaipa Creek. Average weights of individual mayfly nymphs decreased in April, to remain low throughout the summer as large numbers of early instars were recruited into the system. Small average sizes of baetid nymphs persisted through January 1976 in benthic samples, but a large standing crop was present, and larger individuals appeared in the drift (Table 11).

Preferential selection of dipteran larvae by bottom feeding fish seems indicated by data for April 1975 (Fig. 6). Dipteran larvae were relatively abundant in benthic samples at that time, although far less so than mayfly nymphs, yet they comprised a greater proportion of total stomach contents than mayflies in Rhinichthys osculus, Tiaroga cobitis, and Catostomus insignis (Tables 7 - 9; Fig. 6). Other fishes also ate substantial amounts of dipterans, but Meda fulgida and Agosia chrysogaster contained mostly mayfly nymphs, and Pantosteus clarki was feeding heavily upon algae (Fig. 6). A relatively large year class of plecopteran nymphs was also present, and was being cropped by all fish species excepting P. clarki.

Each of these fishes, again excepting P. clarki, ate relatively greater amounts of ephemeropteran nymphs in April, perhaps exploiting the comparatively large, pre-emergence instars that were present.

Dramatic changes in stomach contents of almost all fish species occurred in July, coincident with declines in both dipteran larvae and mayfly nymphs, and a substantial decrease in average individual sizes

Table 11. Mean weights of individual ephemeropteran nymphs, individual baetid ephemeropteran nymphs, and numbers of each per unit sample in benthos and drift from Aravaipa Creek, Arizona, 1975-76.

Items	Jan	Apr	Jul	Oct	Jan
TOTAL EPHEMEROPTERA					
Benthos, wt. in mg	0.84	0.90	0.52	0.47	0.69
No/m^2	974	2,928	2,249	6,115	5,166
Drift, wt. in mg	1.58	0.58	0.51	0.44	1.00
No/m^3	13.30	25.10	9.00	22.40	22.30
BAETIDAE					
Benthos, wt. in mg	0.99	0.90	0.56	0.51	0.30
No/m^2	565	1,851	1,453	4,930	3,552
Drift, wt. in mg	1.73	0.50	0.34	0.62	1.00
No/m^3	8.40	15.70	6.70	14.90	19.20

of the latter (Figs. 6-7; Table 11). Alterations in food habits consisted of a shift by 3 of the 6 species to different prey items. Each of the alternates had increased in relative abundance in July from the previous sampling period.

These changes reflected opportunistic feeding behavior of each fish species within the realm of its respective habitat. Spikedace increased its use of drifting materials, terrestrial and winged aquatic insects, exploiting its mid- to surface water habits. Loach minnows began to prey heavily upon rheophilic trichopteran larvae (in fact, to a degree disproportionate to the indicated abundance of that group; Fig. 6). The third species, Gila coarse-scaled sucker, amplified its cropping of bottom inhabiting turbellarians that had commenced in April, until they made up more than 40% of its total stomach contents in July.

Diversification of diet was minimal in speckled dace, with a small increase in predation upon winged insects being the only obvious change in July. Perhaps this was a response to slight increases in abundance of that food source in summer (Fig. 6). Gila mountain-sucker fed upon turbellarians, to the exclusion of other invertebrates, but this may reflect incidental intake of the abundant flatworms from riffle bottoms. Longfin dace persisted in feeding upon algae in July, along with a consistent ration of mayflies, and even showed a tendency toward supression of diversity of diet in summer and autumn (Fig. 6).

Percentage total stomach volumes of all species decreased dramatically from April levels in July, and remained relatively low through October (Fig. 7). Intuitively, decreased stomach contents would imply a lower availability of foods. Yet changes in qualitative feeding habits

was obvious in only 3 of 6 species. It seems likely that decreased food intake in summer and autumn reflects physiological states of the animals, induced by high summer temperatures, reduced reproductive activity, or some other factor, rather than changes in the food base. However, the parallels in Figure 7 are intriguing, and bear further research.

As mayfly nymphs returned to a more clear-cut position of dominance in the stream in October, average sizes of individual nymphs increased, and alternate food organisms declined in abundance (in 2 instances of 3 recorded), food habits of the fishes shifted back to a pre-July condition. Dipteran larvae failed to increase to their former abundance, however, and were largely replaced in benthic biomass by trichopteran larvae. The fishes generally responded in turn, and trichopterans were consistently present in stomachs of all species except P. clarki in January 1976 (Fig. 6; Tables 5 - 10).

CONCLUSIONS

Various foods in Aravaipa Creek, Arizona, were cropped by the native fishes in general relation to their abundance within the system. All fish species, with the exception of a single herbivore and a facultative omnivore, fed upon the same staple item, ephemeropteran nymphs, and secondarily upon trichopteran or dipteran larvae, or winged insects. The herbivore took in animal food when an item was abundant, and the omnivorous species ate almost as many mayfly nymphs, on the average, as did carnivorous forms, but apparently selected against other food organisms.

The degree to which diets of fishes resemble one another in a given system may have profound affects upon their feeding characteristics

Kawanabe 1959, Keast 1966). At times when foods are plentiful, direct affects of broad overlap in diet may be negligable. However, when foods are scarce, fishes with the greatest similarity in diet will face increased interspecific interactions (Starrett 1950, Zaret and Rand 1971). Competitive pressures will be most severe for those species having narrow or inflexible feeding habits (Kawanabe 1959).

In Aravaipa Creek, abundance of invertebrate foods, coupled with marked spatial partitioning of habitat by the fishes present, seems to preclude severe interspecific competition for food. Even species with limited food habits and feeding repertoire, for example Tiaroga cobitis that ate only 11 of 75 items that were considered available and was almost monophagic on 4 of 5 sampling dates, seemed to have no difficulty in shifting to an alternate food source when mayflies became less abundant. Decreased total stomach volumes in all fishes in July, when the major shifts in food habits occurred, may have related to decreased food supply. However, stomachs remained relatively empty in October after benthos and drift increased, and shifts from alternate food supplies back to mayfly nymphs also had occurred.

Mendelson (1975) similarly found that standing crops of fish food organisms appeared sufficient in Roxbury Creek, Wisconsin, to support larger fish populations than were actually present. Starrett (1950) observed that food was abundant and not an obvious limiting factor for several species of minnows in the Des Moines River, Iowa. All were able to draw from a common food base with little or no apparent competition. If direct competition for food were a significant factor in these systems, greater divergence in diets might be expected (Lawlor and Smith

1976). In situations where little partitioning of the food supply by fishes appears to occur, such as in Aravipa Creek, opportunism appears a common tendency (Mendelson 1975, Keast 1966). When a staple food decreases in abundance, a rapid shift occurs to other, locally or seasonally abundant items. Some species continued to feed, generally upon the same foods throughout the year, while others shifted, each to a different alternate prey. The shift by this last group of fishes implies a sophisticated spatial and behavioral adjustment that allows exploitation of the existing food base without increasing interspecific feeding interactions.

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APPENDIX F

MOVEMENTS OF FISHES IN ARAVAIPA CREEK, ARIZONA

by

Darrell John Siebert

A Theses Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

ARIZONA STATE UNIVERSITY

December 1980

MOVEMENTS OF FISHES IN ARAVAIPA CREEK, ARIZONA

by

Darrell John Siebert

has been approved

August 1980

APPROVED:

______________________________,Chairperson

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Supervisory Committee

ACCEPTED:

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Department Chairperson

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Dean, Graduate College

ABSTRACT

About 2,100 native minnows (Gila robusta Baird and Girard) and suckers (Pantosteus clarki [Baird and Girard], Catostomus insignis Baird and Girard) were tagged for a mark-recapture study of movements in Aravaipa Creek, Arizona, 1978-79. Fish movements radiated seasonally from and toward a central gorge of the stream. Dispersal was from the gorge in winter and toward and into it in summer, the latter presumably in response to high water temperatures. Floods had little influence on movement patterns and home ranges or territories were not evident in most individuals studied.

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W. L. Minckley is gratefully acknowledged for contributing time, insight, and the initial opportunity for this study. He and other members of my graduate committee, David I. Rassmussen and John N. Rinne, provided critical reviews of this manuscript. Without help of students of the 1978 and 1979 fisheries classes at Arizona State University, especially Donald Randall and Paula Mihalick, completion of this study would have been far more difficult. Fred Wood deserves special thanks for graciously providing a place to camp, and for many ideas resulting from his keen, lifelong observations of the Aravaipa Creek area. Permits for collection of fishes were granted by Arizona Game and Fish Department, and access and other assistance were provided by the Defenders of Wildlife (George Whittell Preserve) and the U. S. Bureau of Land Management (Aravaipa Canyon Primitive Area).

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INTRODUCTION

Essentially all research on movements of fishes in streams has been concentrated on sport or commercially important species. Allied with these observations were others indicating that individual fish, and some species, appeared sedentary. A flurry of investigations on movements, lack of movements, homing, and orientation of fishes characterized research in this area of biology in the 1950s and 1960s. During that time and to date no such information has been compiled on species native to the American Southwest. What is known is largely anecdotical, and concerns large, visible species once common, but now rare. Species such as the Colorado River squawfish Ptychocheilus lucius Girard, and razorback sucker, Xyrauchen texanus (Abbott), reportedly "ran" upstream in great numbers in now-dry master streams of the region in spring, earning in the case of the former the name of "white salmon of the Colorado" (Miller 1961, Minckley 1973).

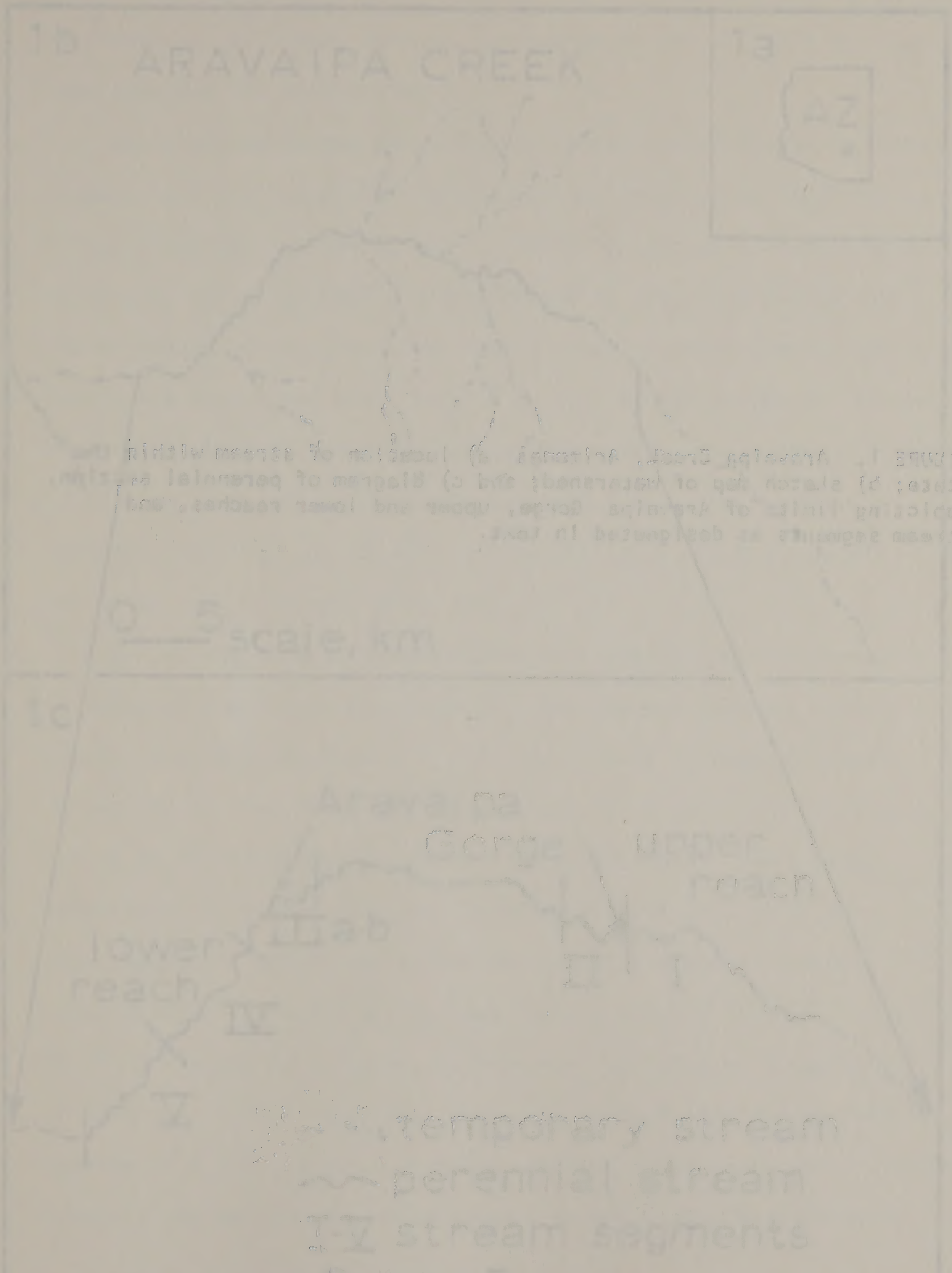
Aravaipa Creek, southeastern Arizona, supports a nearly intact, native fish fauna (Barber and Minckley 1966). The present study of some of these fishes was undertaken with hopes of providing insight into movements in a Southwestern riverine environment, and began with the emperical observation that large, long-lived fishes were seasonally abundant, then essentially absent, from some reaches of the system.

DESCRIPTION OF THE AREA

Aravaipa Creek has been described by a number of investigators, and the following summarizes those sources plus my own observations on aspects deemed pertinent to the present report. References for additional information include Barber and Minckley (1966), Bruns and Minckley (1980), Minckley (1980), and references cited.

Perennial flow surfaces from gravelly substrate approximately 6.5 km northwest of Klondyke, Graham County, Arizona, maintains surface discharge for about 40 stream-km, then typically recedes into its bed 7.6 km upstream from the confluence with the San Pedro River, Pinal County (Fig. 1a-b). The upper 10 km flows through a broad, open valley. A central portion passes for about 17 stream-km through the narrow Aravaipa Canyon (10 to 100 m wide; hereafter termed Aravaipa Gorge), between sheer walls that rise to more than 200 m above the stream. The gorge then widens to consist of a steep-sided valley cut in sloping bajada deposits of the Galiuro Mountains along its last 14 km. Surface water from Aravaipa Creek enters the typically dry San Pedro River only in times of unusually high and sustained discharge.

Patterns of discharge for streams in southeastern Arizona are highly seasonal, variable, and generally low in volume (Burkham 1970). Base (modal) discharge in winter in Aravaipa Creek is 0.32 m^3/s. A strongly bimodal pattern is evident in summer, with a low mode of 0.14 m^3/s and an upper level near 0.28 m^3/s. Low discharge is maintained by springs and seepage from the aquifer, and the higher mode is presumably a result of summer spates from local rainfall on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Aravaipa Gorge
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lower reach
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IV
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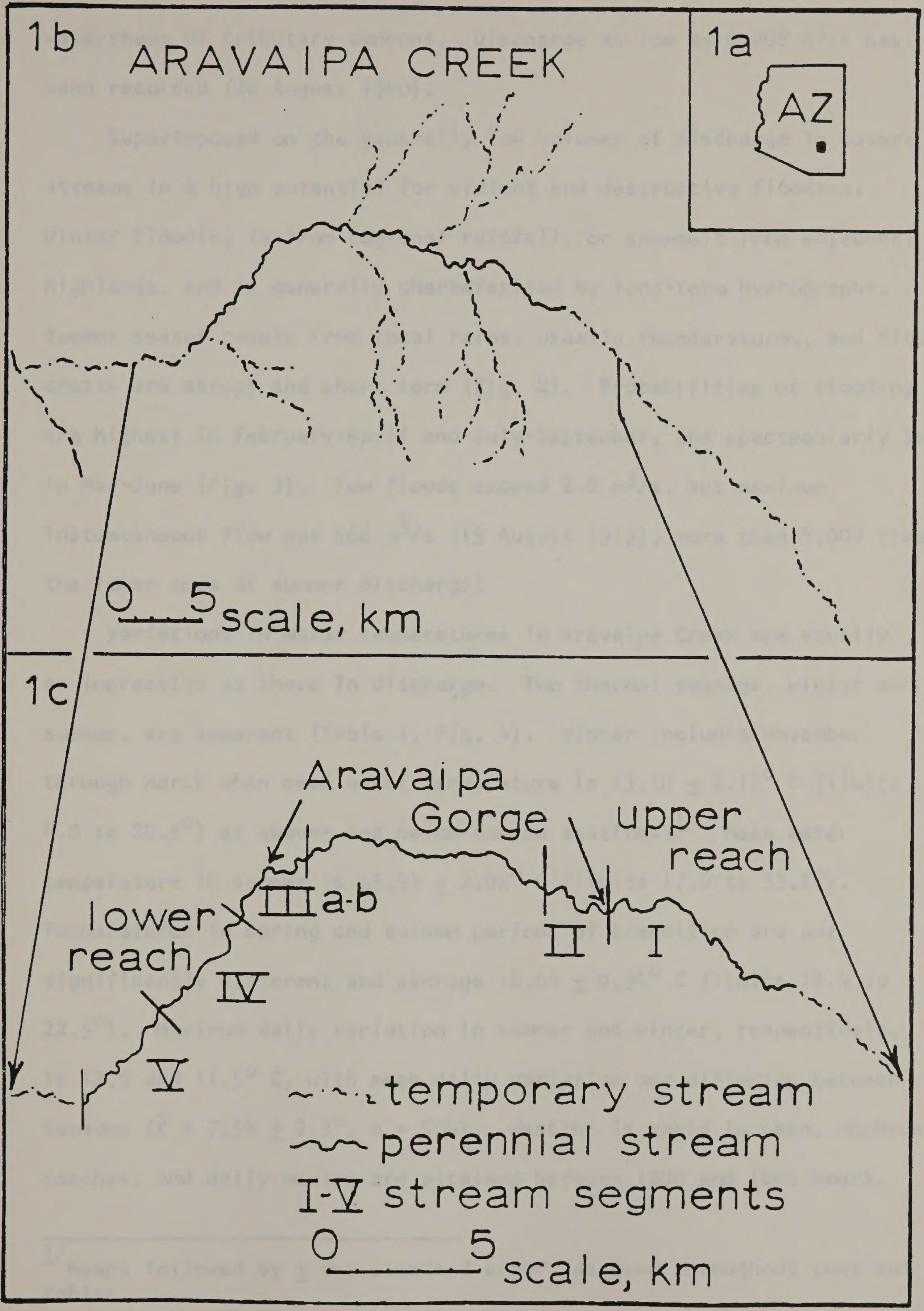
temporary stream
perennial stream
I-V stream segments
0 5 scale, km

FIGURE 1. Aravaipa Creek, Arizona: a) location of stream within the state; b) sketch map of watershed; and c) diagram of perennial section, depicting limits of Aravaipa Gorge, upper and lower reaches, and stream segments as designeted in text.


1b
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IV
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temporary stream
perennial stream
I-V stream segments
0 5 scale, km

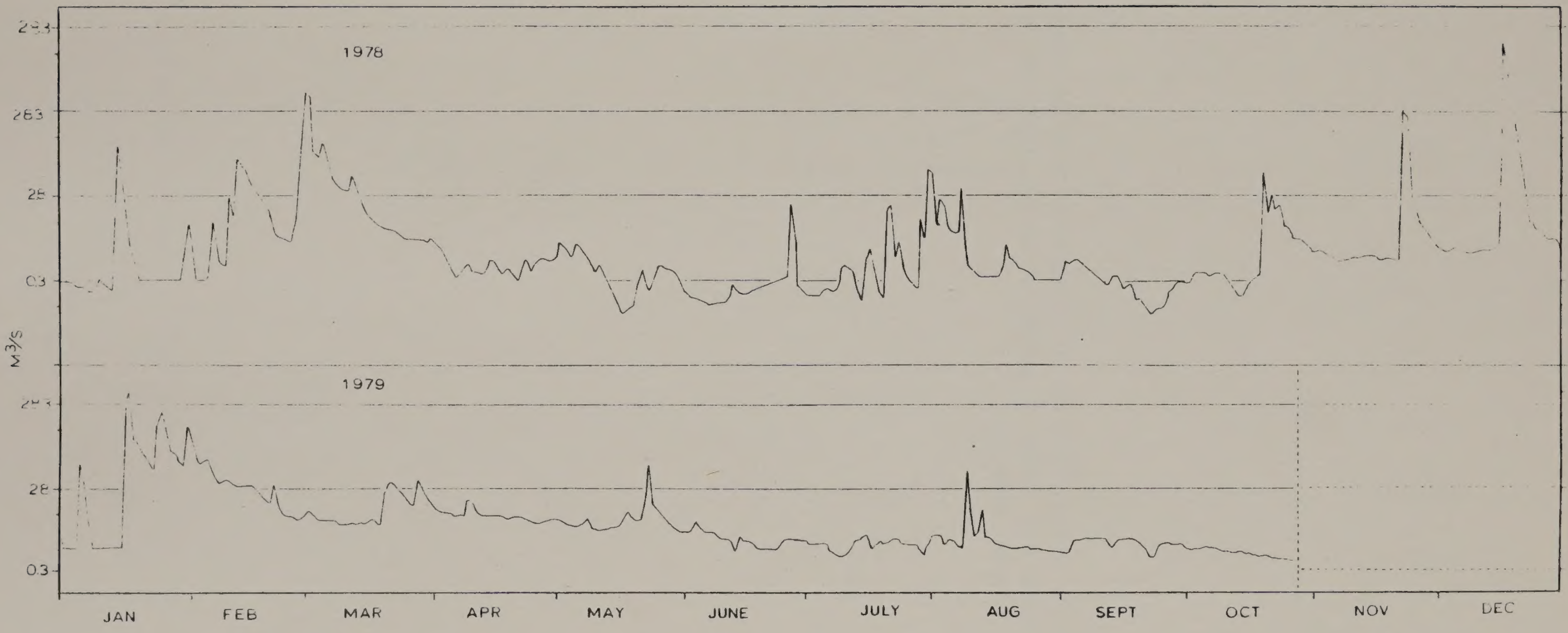
watersheds of tributary canyons. Discharge as low as 0.008 m^3/s has been recorded (20 August 1940).

Superimposed on the generally low volumes of discharge in desert streams in a high potential for violent and destructive flooding. Winter flooding is from regional rainfall, or snowmelt from adjacent highlands, and is generally characterized by long-term hydrographs. Summer spates result from local rains, usually thunderstorms, and flood crests are abrupt and short term (Fig. 2). Probabilities of flooding are highest in February-April and July-September, and spectacularly low in May-June (Fig. 3). Few floods exceed 2.0 m^3/s, but maximum instantaneous flow was 566 m^3/s (19 August 1919), more than 4,000 times the lower mode of summer discharge!

Variations in water temperatures in Aravaipa Creek are equally as impressive as those in discharge. Two thermal seasons, winter and summer, are apparent (Table 1, Fig. 4). Winter includes November through March when mean water temperature is $13.10 \pm 2.17^\circ$ C (limits 4.0 to 20.5°) at above- and below canyon stations.[1/] Mean water temperature in summer is $23.93 \pm 2.02^\circ$ C (limits 17.0 to 33.2°). Temperatures in spring and autumn periods of transition are not significantly different and average $16.64 \pm 0.94^\circ$ C (limits 12.4 to 22.5°). Maximum daily variation in summer and winter, respectively, is 12.5 and 11.5° C, with mean daily variation not differing between seasons ($\overline{X} = 7.58 \pm 2.3^\circ$, n = 504). Heating is rapid in open, unshaded reaches, and daily maxima are attained between 1200 and 1600 hours.

[1/] Means followed by ± one standard error, as used throughout text and tables.

FIGURE 2. Mean daily discharges of Aravaipa Creek, Arizona, 1978-79; from provisional records of the U. S. Geological Survey, Tucson, Arizona.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1978
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28
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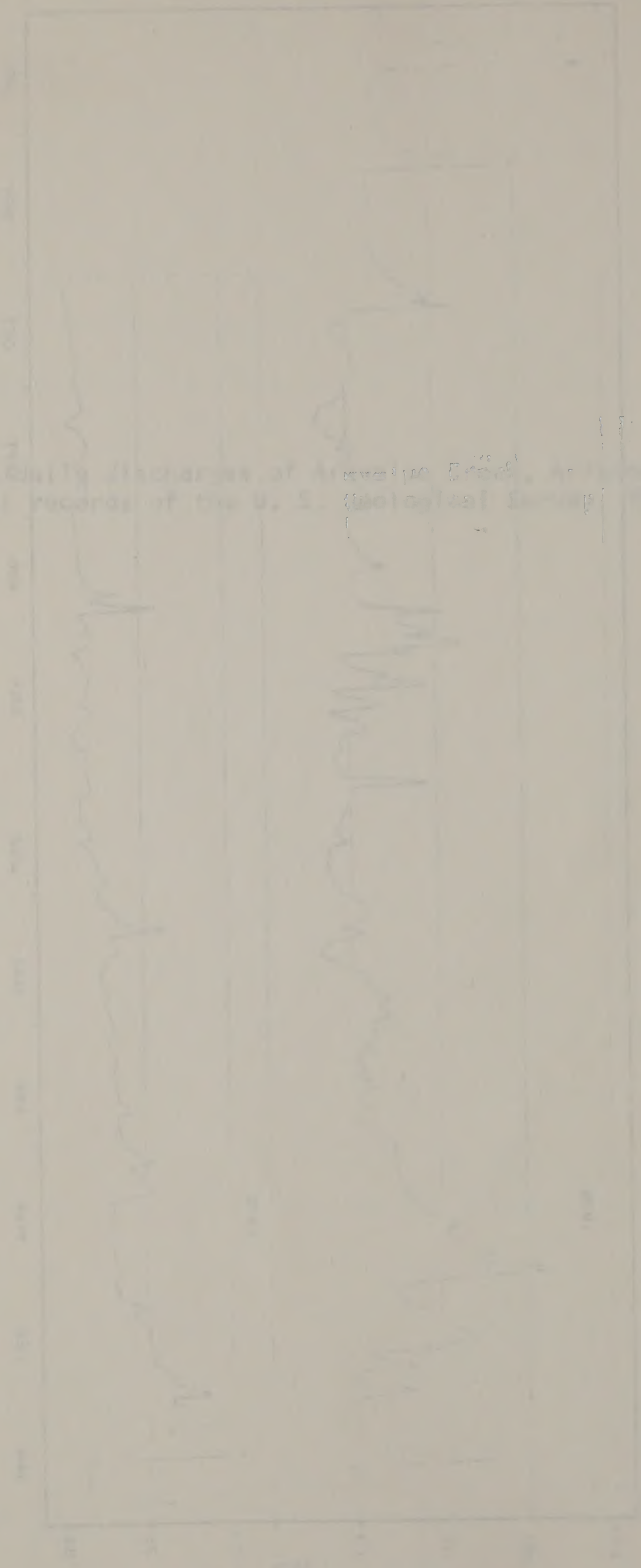

FIGURE 1. Mean daily discharges of Aravaipa Creek, Arizona, [illegible], from provisional records of the U. S. Geological Survey, Tucson, Arizona.

FIGURE 3. Monthly probabilities of flooding greater than indicated levels of discharge. Computed from 13 years of data, 1967-79 (U. S. Geological Survey 1975 and unpublished).

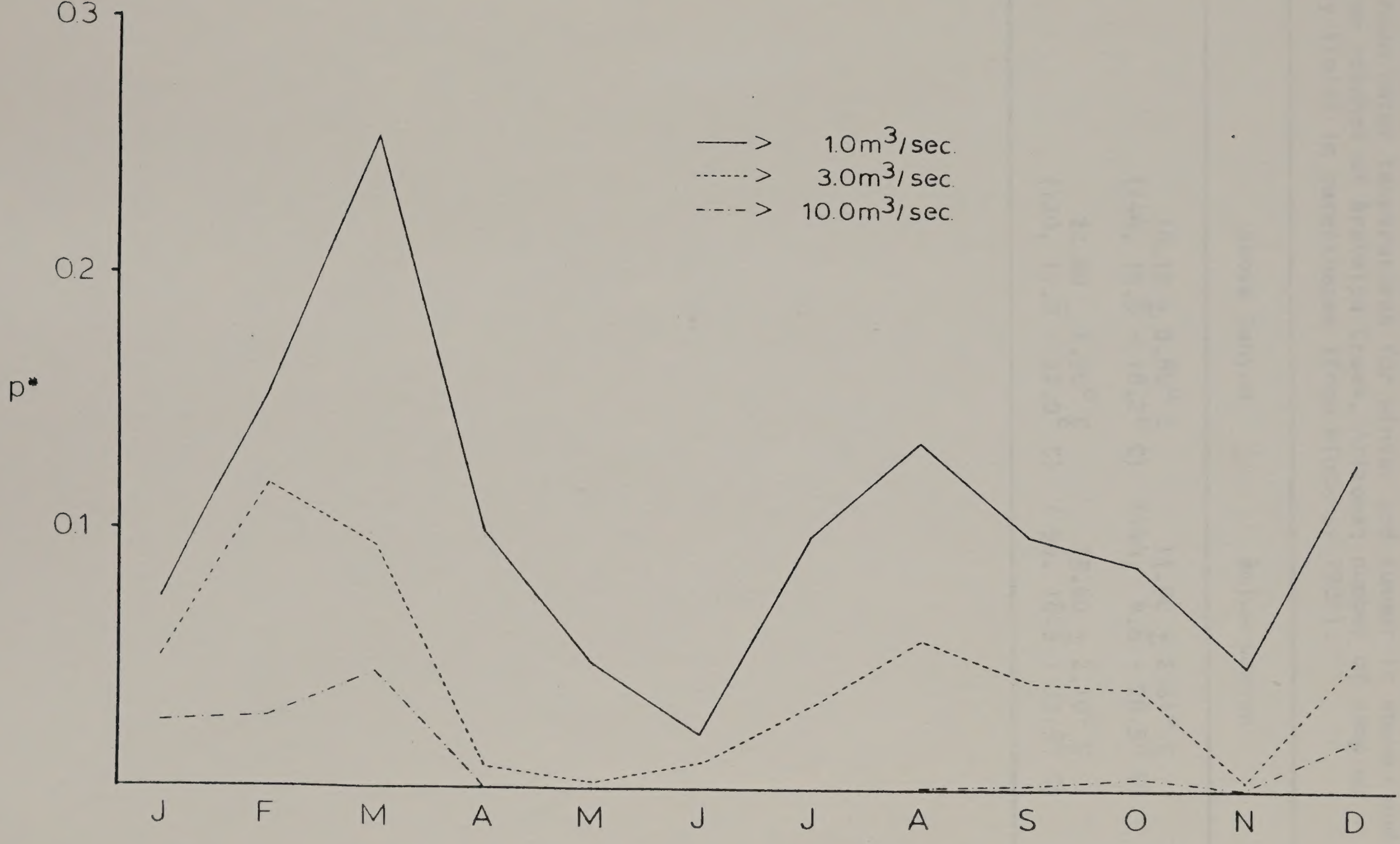
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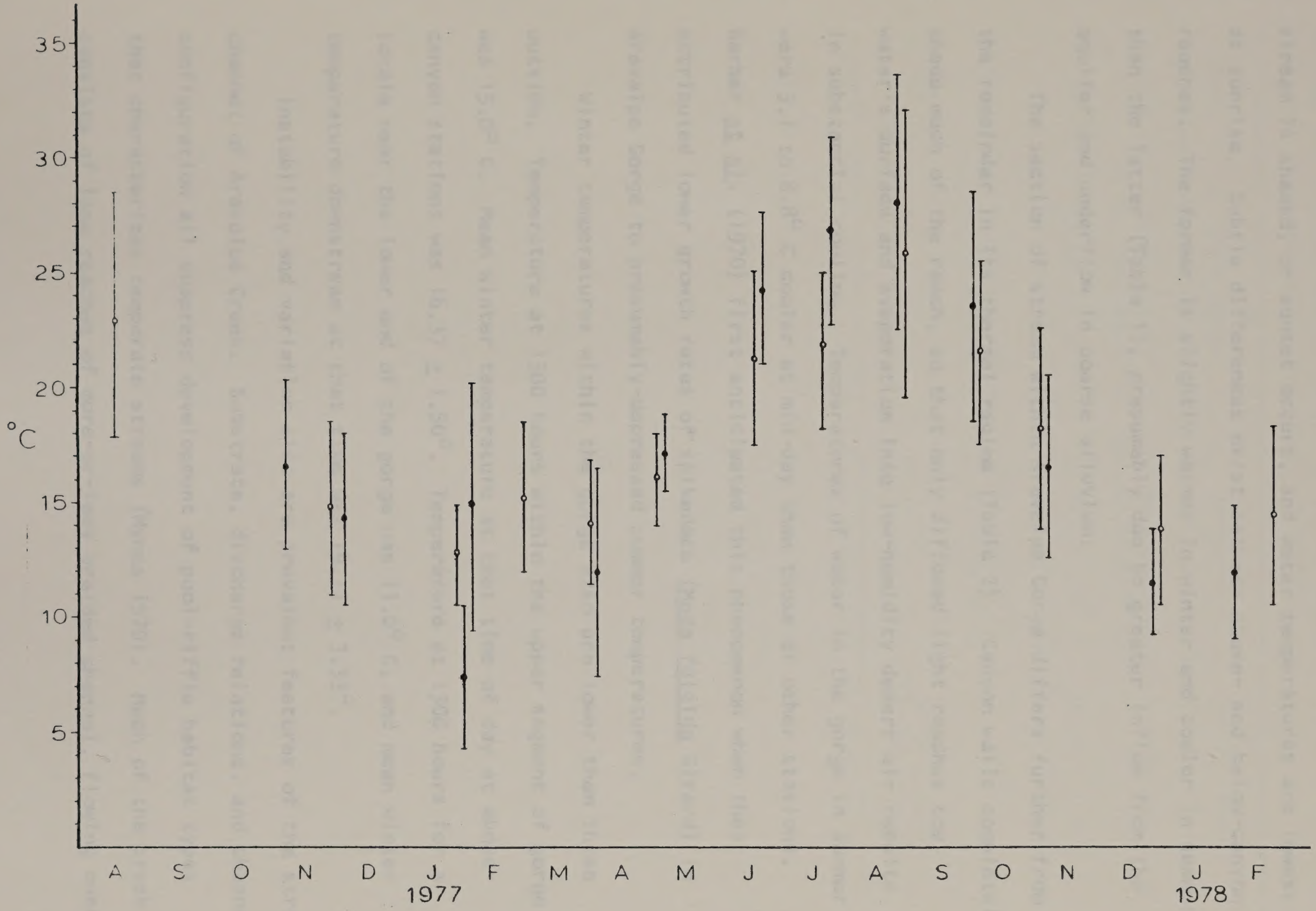
FIGURE 3. Monthly probabilities of flooding greater than indicated levels of discharge. (Computed from 19 years of data 1957-75 (U. S. Geological Survey 1975 and unpublished)).

TABLE 1. Mean water temperatures for winter and summer in above- and below-canyon reaches of Aravaipa Creek, Arizona; number of samples followed by limits in parentheses (from Minckley 1980).

Seasons	Above Canyon	Below Canyon
Winter	14.13 ± 0.82° C (144, 10.5 - 18.2° C)	11.90 ± 2.61° C (144, 4.6 - 20.5° C)
Summer	22.60 _ 1.96° C (120, 17.0 - 32.0° C)	25.60 ± 2.10° C (96, 18.5 - 33.5° C)

FIGURE 4. Means and ranges of water temperatures for above- (open circles) and below canyon stations (dots) in Aravaipa Creek, Arizona. Computed as the mean of maximum and minimum daily temperatures (Macan 1958).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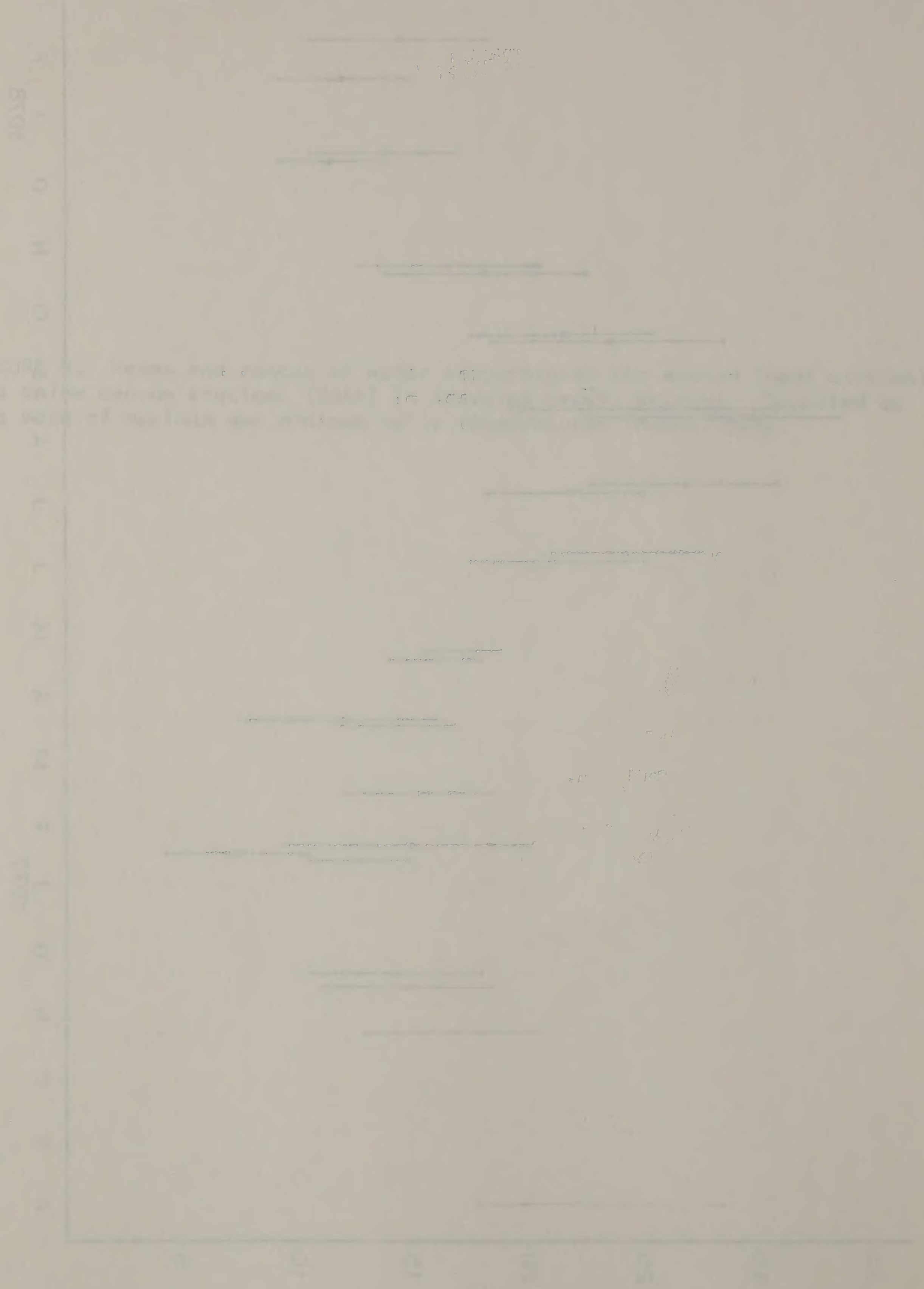


FIGURE 9. Range and means of water temperatures at the surface (upper bars) and below canopy surface (lower) in [illegible]
[illegible]

Cooling also is rapid, once angle of incident light becomes low, the stream is shaded, or sunset occurs, and water temperatures are lowest at sunrise. Subtle differences exist between above- and below-canyon reaches. The former is slightly warmer in winter and cooler in summer than the latter (Table 1), presumably due to greater inflow from the aquifer and underflow in coarse alluvium.

The section of stream within Aravaipa Gorge differs further from the remainder in its thermal regime (Table 2). Canyon walls completely shade much of the reach, so that only diffused light reaches the water's surface and evaporation into low-humidity desert air results in substantial cooling. Temperatures of water in the gorge in summer were 3.1 to 8.8° C cooler at mid-day than those at other stations. Barber et al. (1970) first anticipated this phenomenon when they attributed lower growth rates of spikedace (Meda fulgida Girard) in Aravaipa Gorge to presumably-depressed summer temperatures.

Winter temperatures within the gorge also are lower than those outside. Temperature at 1300 hours within the upper segment of gorge was 15.0° C. Mean winter temperature at that time of day at above-canyon stations was 16.37 ± 1.50°. Temperature at 1300 hours for a locale near the lower end of the gorge was 11.0° C, and mean winter temperature downstream at that time was 14.11 ± 3.33°.

Instability and variation also are prevalent features of the stream channel of Aravaipa Creek. Substrate, discharge relations, and channel configuration all suppress development of pool-riffle habitat types that characterizes temperate streams (Hynes 1970). Much of the creek consists of long reaches of more-or-less braided channel, flowing over

TABLE 2. Mean water temperatures at mid-day on selected dates above, within, and below Aravaipa Gorge, Arizona; number of samples followed by limits in parentheses (from Minckley 1980).

Dates	Above Canyon	Within	Below Canyon
10-VIII-76	26.68 ± 1.33° C (4, 24.3-28.4° C)	22.75 ± 1.10° C (4, 22.0-24.3° C)	-----
5- VI -77	22.88 ± 1.77° C (8, 21.0-25.0° C)	19.74 ± 1.14° C (5, 19.0-24.3° C)	26.00 ± 1.10° C (6, 25.0-27.5° C)
9-VII -77	25.05 ± 0.18° C (4, 24.5-25.5° C)	21.27 ± 0.86° C (3, 20.5-22.3° C)	-----
10-VII -77	-----	-----	30.08 ± 0.29° C (4, 29.5-32.0° C)

coarse gravel and sand. Such runs are separated at irregular intervals by short, turbulent riffles that are less than 15 cm deep at modal discharges. Riffle substrates are coarse gravel, cobble, and small boulder. Pools are infrequent and appear only where canyon walls, boulders, or an occasional fallen tree obstruct flow and induce scour. Pools scoured around and beneath such obstructions are 0.75 to 1.0 m deep, and occasionally to 1.5 m. Bottoms are usually unstable in such habitats as a result of continuous transport of sand by local turbulence, and pools other than those maintained by the most permanent features are transient. Flooding displaces logs and boulders and fills scour basins with sand, and in wider places the channel may move, isolating pools in one place and creating others nearby.

METHODS AND MATERIALS

Three of the seven native fishes inhabiting Aravaipa Creek attain a large enough size, 10 cm or more in total length (Fig. 5), to be marked with anchor tags. One, _Gila_ _robusta_ Baird and Girard) (roundtail chub) is a minnow (Cyprinidae), and two are suckers (Catostomidae), _Pantosteus_ _clarki_ (Baird and Girard) (desert mountain-sucker) and _Catostomus_ _insignis_ Baird and Girard (Sonoran sucker). Fishes were captured by electrofishing apparatus delivering an alternating current of 115 volts and 0.6 amps. Care was taken to avoid over-exposure of stunned fishes to electricity, current being applied only to allow dip-netting.

Fishes were marked with a colored, individually numbered, anchor tag obtained from Floy Tag and Manufacturing Company, Seattle, Washington, inserted by needled tagging gun through the dorsal musculature and secured among medial pterygiophores of the dorsal fin. Implanted tags trailed posterolaterally along the dorsolateral surface. Potassium permangenate solution was applied to the tagging wound to minimize susceptibility to infections. Marking mortality and tag loss were not assessed, but were considered low. Few fish ever exhibited scarring where a tag would have been shed, and little mortality was evident on a 24-hour basis following marking.

Tags consisted of a nylon crossbar anchor and 60-mm shaft over which a 1.75-mm (outside diameter), colored, 45-mm-long vinyl tube was fitted. A combination of tube color and number provided each fish with a permanent, unique identifier. Use of tag color proved impractical, however, without the fish in hand, because of over-growth by algae.

FIGURE 5. Size-frequency distribution of fishes tagged and recaptured in Aravaipa Creek, Arizona, 1978-79. Four hybrid catostomids were excluded, thus n = 241 fishes.

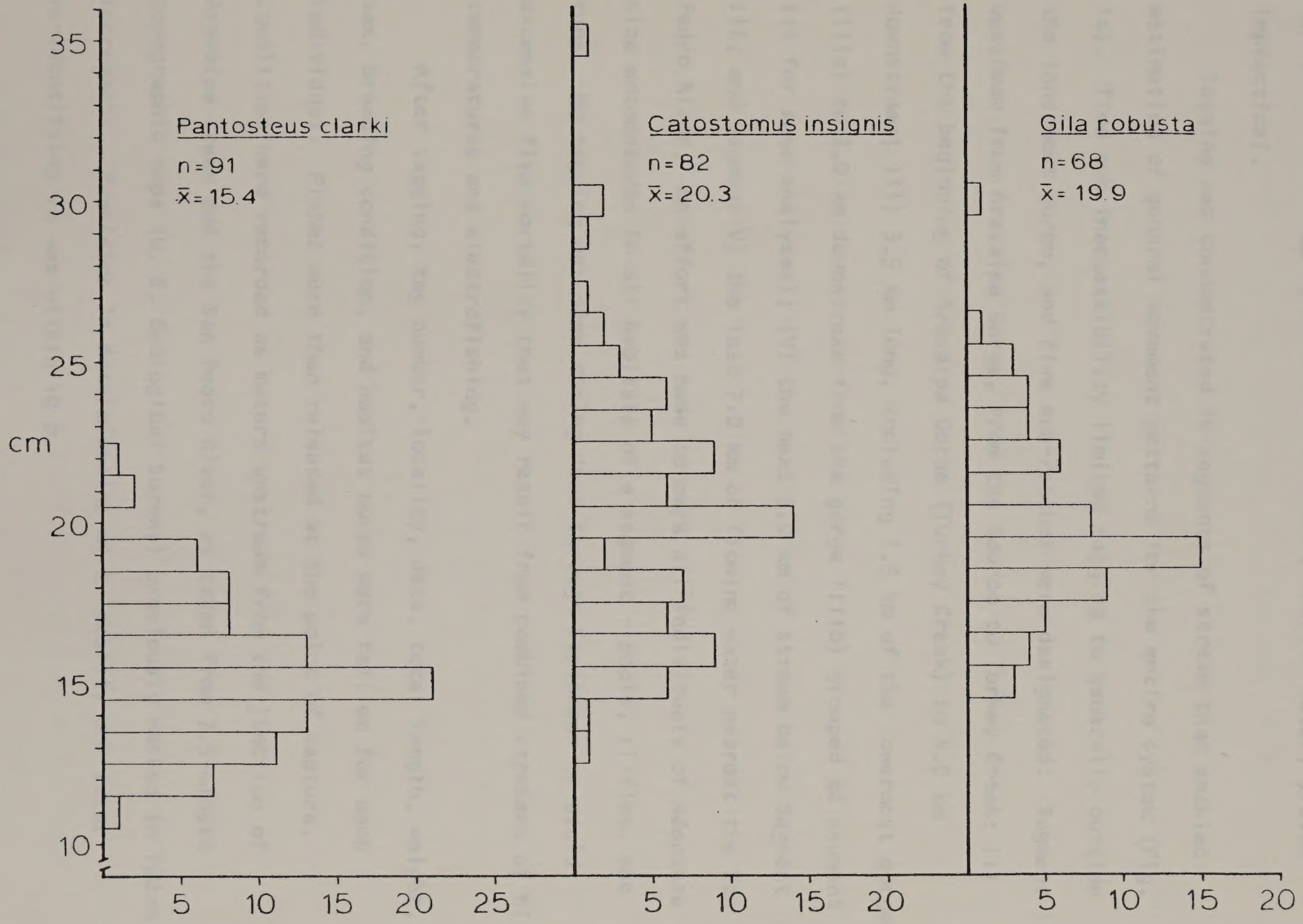

Pantosteus clarki
n = 91
x̄ = 15.4
Catostomus insignis
n = 82
x̄ = 20.3
Gila robusta
n = 68
x̄ = 19.9
cm
35
30
25
20
15
10
5
10
15
20
25
5
10
15
20
5
10
15
20

FIGURE 5. Size-frequency distributions of [illegible] in Aravaipa Creek, Arizona, 1978-79. Four hybrid catostomids were excluded, thus n = 281 fishes.

Further, discrimination of certain tag colors, e.g. shades of orange vs. yellow, blue vs. green, even in clear, shallow water, proved impractical.

Tagging was concentrated in segments of stream that enabled estimation of general movement patterns for the entire system (Fig. 1c). Time and inaccessibility limited tagging to generally outside the innermost gorge, and five sub-reaches were designated: Segment I) upstream from Aravaipa Gorge, from the source to Turkey Creek; II) from the beginning of Aravaipa Gorge (Turkey Creek) to 4.0 km downstream; III) 3.5 km long, including 1.5 km of the lowermost gorge (IIIa) to 2.0 km downstream from the gorge (IIIb) grouped as segment III for some analyses); IV) the next 5.0 km of stream below Segment III; and Segment V) the last 7.0 km of flowing water nearest the San Pedro River. An effort was made to mark all individuals of adequate size encountered in all habitats of a segment - pools, riffles, and runs. No tagging was done during June through September to avoid excessive fish mortality that may result from combined stresses of high temperatures and electrofishing.

After tagging, tag number, locality, date, total length, weight, sex, breeding condition, and habitat notes were tallied for each individual. Fishes were then released at the point of capture. Localities were recorded as meters upstream from the junction of Aravaipa Creek and the San Pedro River, as taken from 7.5-minute topographic maps (U. S. Geological Survey) previously marked in 100-m increments. Precision in determination of a locality and later re-identifying it was within 10 m.

Fish movements were followed by direct recapture of previously tagged individuals from throughout Aravaipa Creek. Sampling was bi-weekly to monthly during the period from September through May, and every six weeks from June through August, for 22 months beginning January 1978. Minimum distances moved were calculated by subtraction of the point of original capture or any point of earlier recapture from the place of recapture on a later date. Thus the sign of the result indicated direction of movement, a positive difference indicating travel upstream and a negative difference, downstream dispersal.

Computations for analysis of variance and linear regression were done by Univac 1110/42 Computer, using programs from the 1975 version BMDP Package (Dixon 1975). Groupings for analysis of variance were by sex, species, segment in which a fish was tagged, and season. Regression analysis was used to study relations between distances moved and total length, and between distances and locality of tagging. Randomness of movement (or lack of such) was examined by treatment of each fish's travel as a Bernoulli trial, with two possible outcomes — upstream or downstream — and a probability (p^*) of either of 0.5. Distribution of outcomes of trials was then compared to the binomial distribution and probability of the observed distribution occurring by chance was computed. Fishes were grouped for this analysis by stream segment and by season. For analytical purposes designations of seasons follows the pattern given earlier for the thermal regime of Aravaipa Creek (winter and summer). Upper Aravaipa Creek is defined as above the gorge (Segment I), and lower Aravaipa Creek is below that reach (Segments IIIb-V).

RESULTS

Almost 2,100 fishes were tagged in Aravaipa Creek, of which 219 (10.4%) were recaptured at least once and 23 were caught 2 or more times (Table 3). One Sonoran sucker was captured on five separate occasions.

All fishes tagged in Aravaipa Creek were inclined to move. Most individuals recaptured (83.7% in the lower segments and 80.5% in upper segments) had moved more than 100 m from the point of tagging. Distances moved by fishes up- or downstream were considerable, and those of a few were spectactular (Fig. 6). Differences in mean distances moved were not significant among species (Fig. 7), or between sexes (Fig. 8).

For purposes of analysis, fishes which moved less than 100 m were considered to have not moved at all, an assumption that appears valid since no individual of this group moved further than 60 m from its point of initial marking (Fig. 6). This distance is well within limits of home ranges calculated for other fish species, and particularly for other catostomid species in Indiana (Gerking 1953).

Analysis by stream segments reveals that fish movements were directed into and out of Aravaipa Gorge. Since that reach is in the middle of the stream (Fig. 1c), movement to achieve a position within it from opposing ends, or a position outside from within, must be in opposite directions. Fishes tagged in Segment II moved upstream, a direction that took them away from the gorge toward Segment I ($\bar{X} = +3.718 \pm 10.889$ m [X 100], n = 96), and fish tagged within the lowermost reach of the gorge (Segment IIIa) moved down

TABLE 3. Numbers of fishes tagged (T) and recaptured (R) one or more times from Aravaipa Creek, Arizona, 1978-79.

Reach	*Gila robusta*		*Catostomus insignis*		*Pantosteus clarki*		Total	
	T	R	T	R	T	R	T	R
Segments I-II	396	55	679	33	281	64	1,366	152
Segments III-V	344	14	269	50	118	29	731	93
Total	740	69	948	83	409	93	2,097	245

FIGURE 6. Distances moved (m X 100) by fishes up- and downstream from points of tagging in Aravaipa Creek, 1978-79.

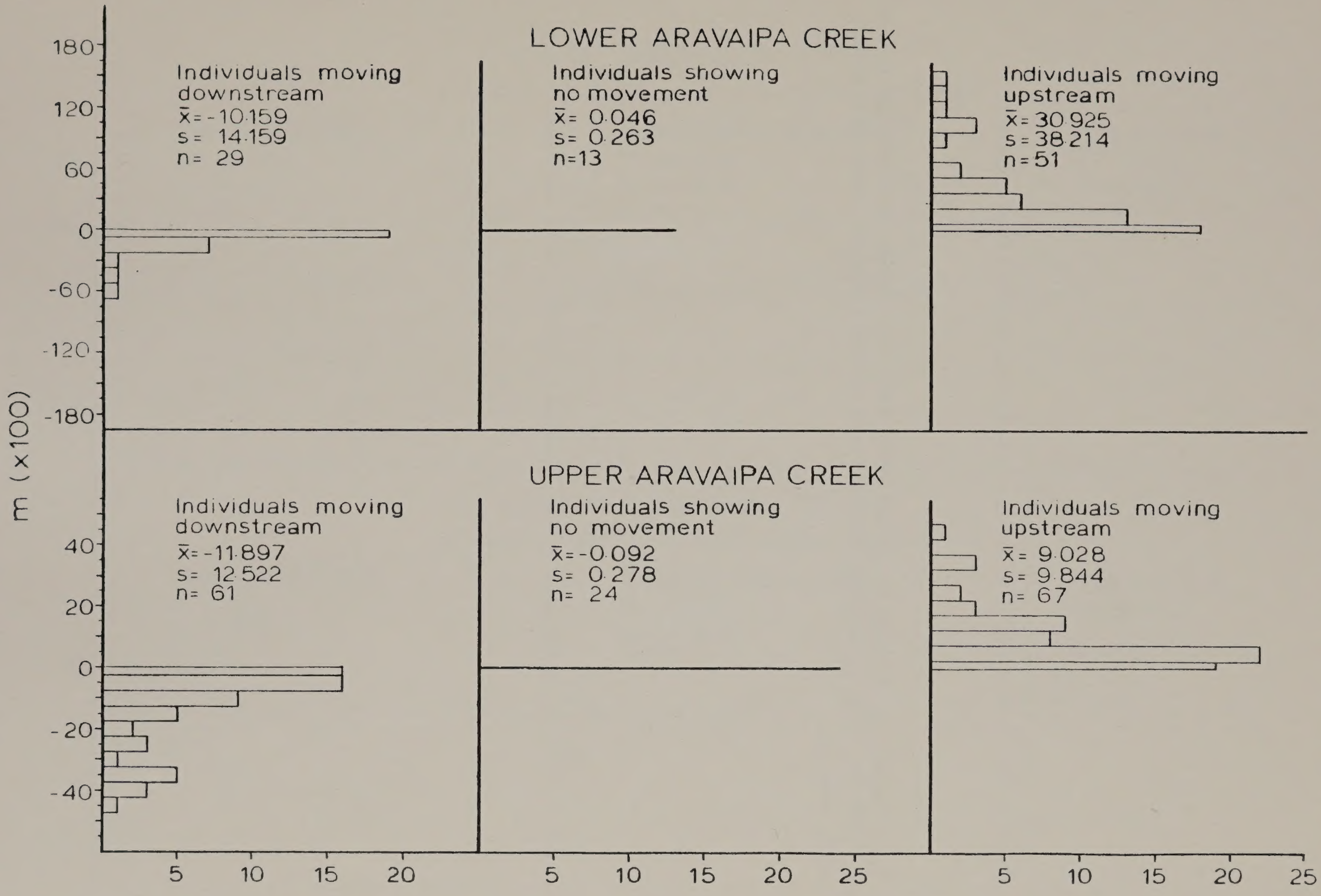

LOWER ARAVAIPA CREEK
Individuals moving downstream
x̄= -10.159
s= 14.159
n= 29
Individuals showing no movement
x̄= 0.046
s= 0.263
n=13
Individuals moving upstream
x̄= 30.925
s= 38.214
n= 51
180
120
60
0
-60
-120
-180
m (x100)
UPPER ARAVAIPA CREEK
Individuals moving downstream
x̄= -11.897
s= 12.522
n= 61
Individuals showing no movement
x̄= -0.092
s= 0.278
n= 24
Individuals moving upstream
x̄= 9.028
s= 9.844
n= 67
40
20
0
-20
-40
5
10
15
20
5
10
15
20
25
5
10
15
20
25

FIGURE 7. Summary of distances moved (m X 100) by fishes in Aravaipa Creek, Arizona, 1978-79, with a summary of analysis of variance of mean distances moved among species.

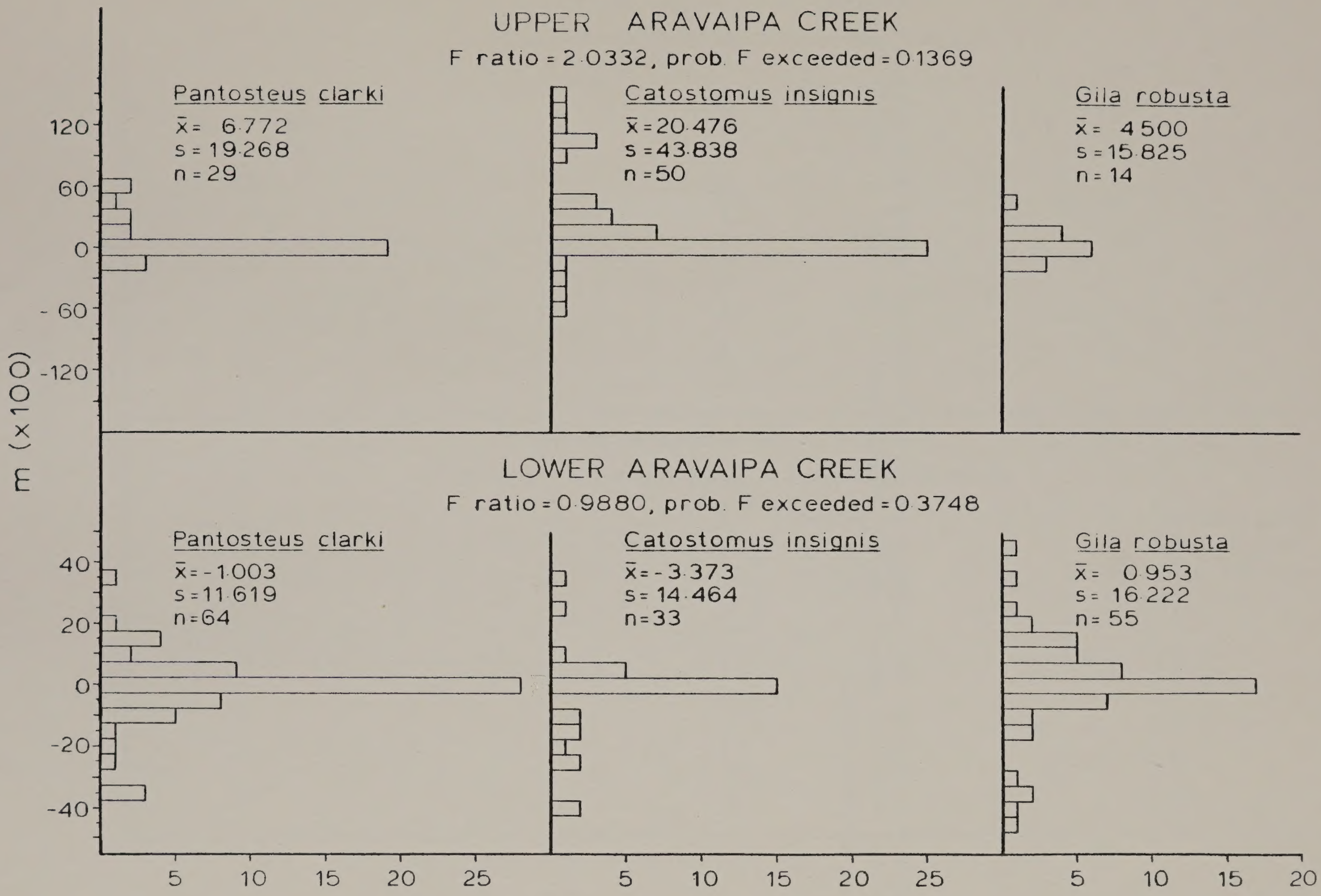
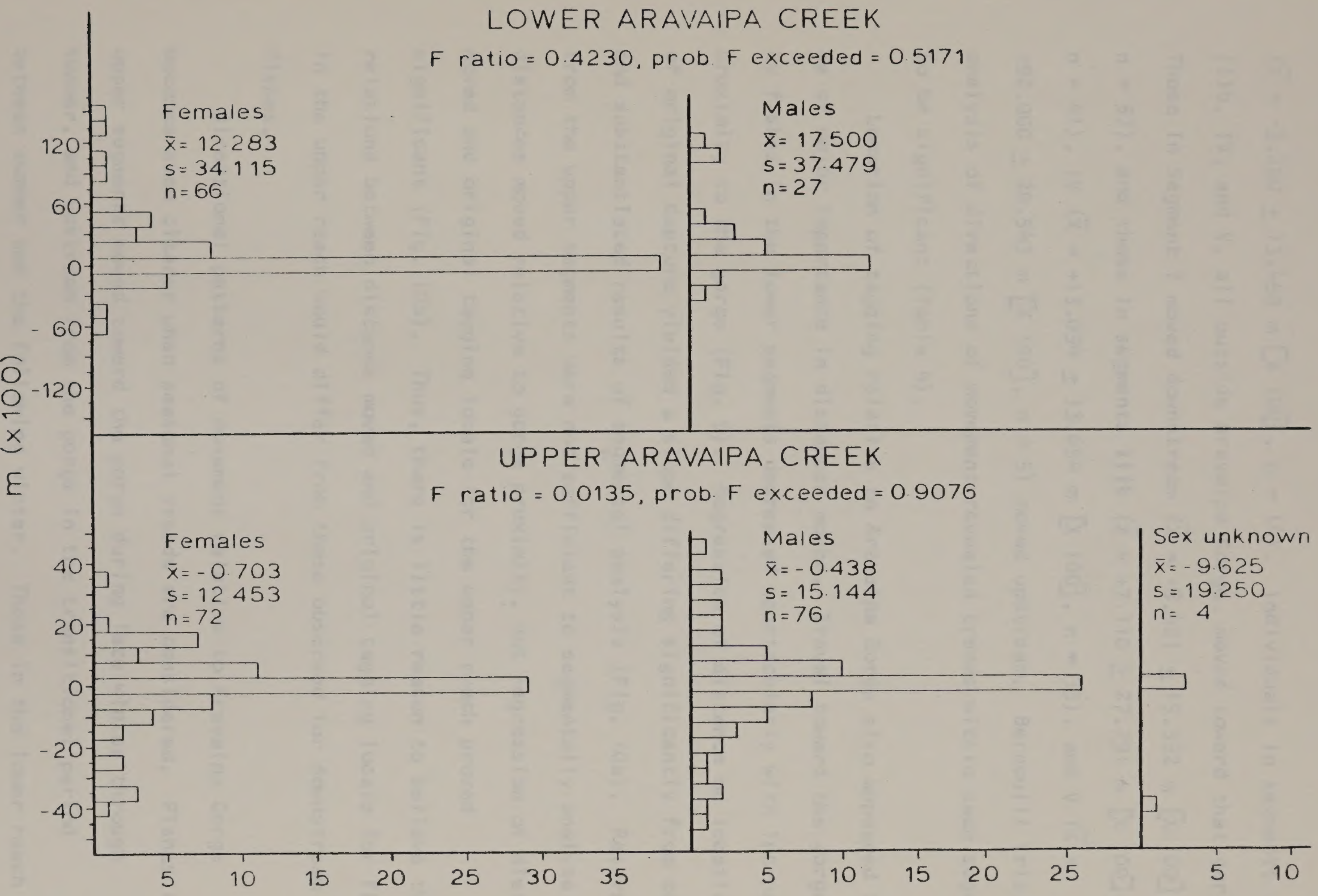

UPPER ARAVAIPA CREEK
F ratio = 2.0332, prob. F exceeded = 0.1369
Pantosteus clarki
x̄ = 6.772
s = 19.268
n = 29
Catostomus insignis
x̄ = 20.476
s = 43.838
n = 50
Gila robusta
x̄ = 4.500
s = 15.825
n = 14
LOWER ARAVAIPA CREEK
F ratio = 0.9880, prob. F exceeded = 0.3748
Pantosteus clarki
x̄ = -1.003
s = 11.619
n = 64
Catostomus insignis
x̄ = -3.373
s = 14.464
n = 33
Gila robusta
x̄ = 0.953
s = 16.222
n = 55
m (x100)
120
60
0
-60
-120
40
20
0
-20
-40
5
10
15
20
25
5
10
15
20
25
5
10
15
20

FIGURE 8. Summary of distances moved (m X 100) by fishes in Aravaipa Creek, Arizona, 1978-79, with a summary of analysis of variance of mean distance moved between sexes.

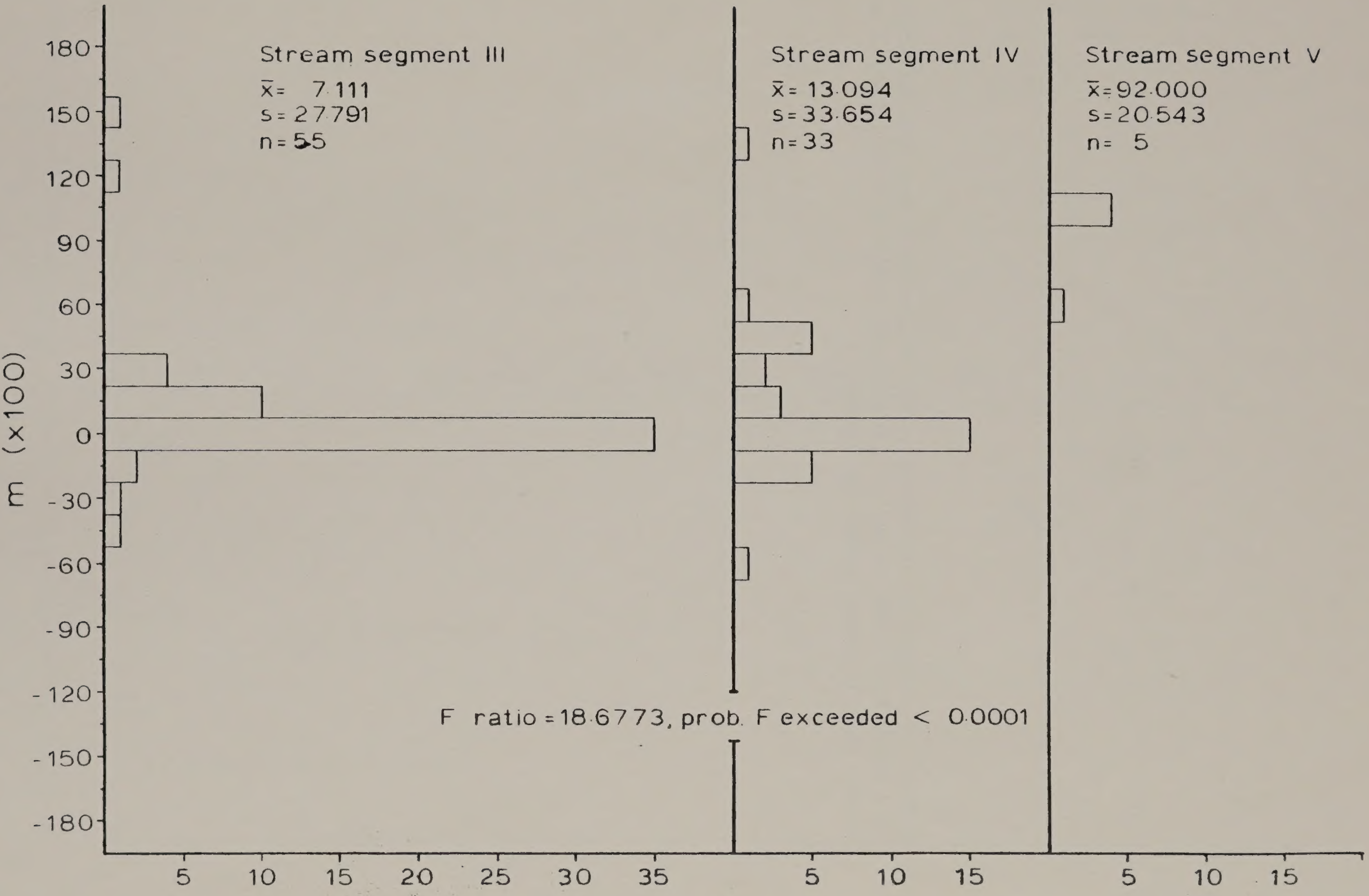

LOWER ARAVAIPA CREEK
F ratio = 0.4230, prob. F exceeded = 0.5171
Females
x̄ = 12.283
s = 34.115
n = 66
Males
x̄ = 17.500
s = 37.479
n = 27
UPPER ARAVAIPA CREEK
F ratio = 0.0135, prob. F exceeded = 0.9076
Females
x̄ = -0.703
s = 12.453
n = 72
Males
x̄ = -0.438
s = 15.144
n = 76
Sex unknown
x̄ = -9.625
s = 19.250
n = 4
m (x100)
120
60
0
-60
-120
40
20
0
-20
-40
5
10
15
20
25
30
35
5
10
15
20
25
5
10

($\bar{X} = -3.200 \pm 13.450$ m [X 100], n = 14). Individuals in segments I, IIIb, IV, and V, all outside Aravaipa Gorge, moved toward that gorge. Those in Segment I moved downstream ($\bar{X} = -8.421 \pm 15.392$ m [X 100], n = 57), and those in segments IIIb ($\bar{X} = +7.110 \pm 27.791$ m [X 100], n = 41), IV ($\bar{X} = +13.094 \pm 33.654$ m [X 100], n = 33), and V ($\bar{X} = +92.000 \pm 20.543$ m [X 100], n = 5) moved upstream. Bernoulli trial analysis of directions of movement revealed trends within each segment to be significant (Table 4).

Location of tagging relative to Aravaipa Gorge also appeared to be of major importance in distances moved. Travel toward the gorge by fishes in the lower segments decreased spectacularly with increased proximity to the gorge (Fig. 9). Regression of distance on location of original capture yielded a slope differing significantly from zero and substantiated results of segmental analysis (Fig. 10a). Returns from the upper segments were not sufficient to segmentally analyse distances moved relative to gorge proximity, but regression of distance moved and original tagging locale for the upper reach proved significant (Fig. 10b). Thus, there is little reason to believe that relations between distance moved and original tagging locale for fishes in the upper reach would differ from those observed for downstream fishes.

Directional patterns of movement relative to Aravaipa Gorge becomes even clearer when seasonal trends are considered. Fishes in upper segments moved toward the gorge during late winter through summer, and upstream from the gorge in the transitional period between summer and the following winter. Those in the lower reach

FIGURE 9. Distance moved (m X 100) by fishes in various segments of Aravaipa Creek, Arizona, 1978-79, with a summary of analysis of variance of mean distances moved among segments.



F ratio = 18.6773, prob. F exceeded < 0.0001

FIGURE 10. Summary information for regression analysis of distance moved (m X 100) by fishes relative to tagging locality: a) lower Aravaipa Creek; and b) upper Aravaipa Creek.

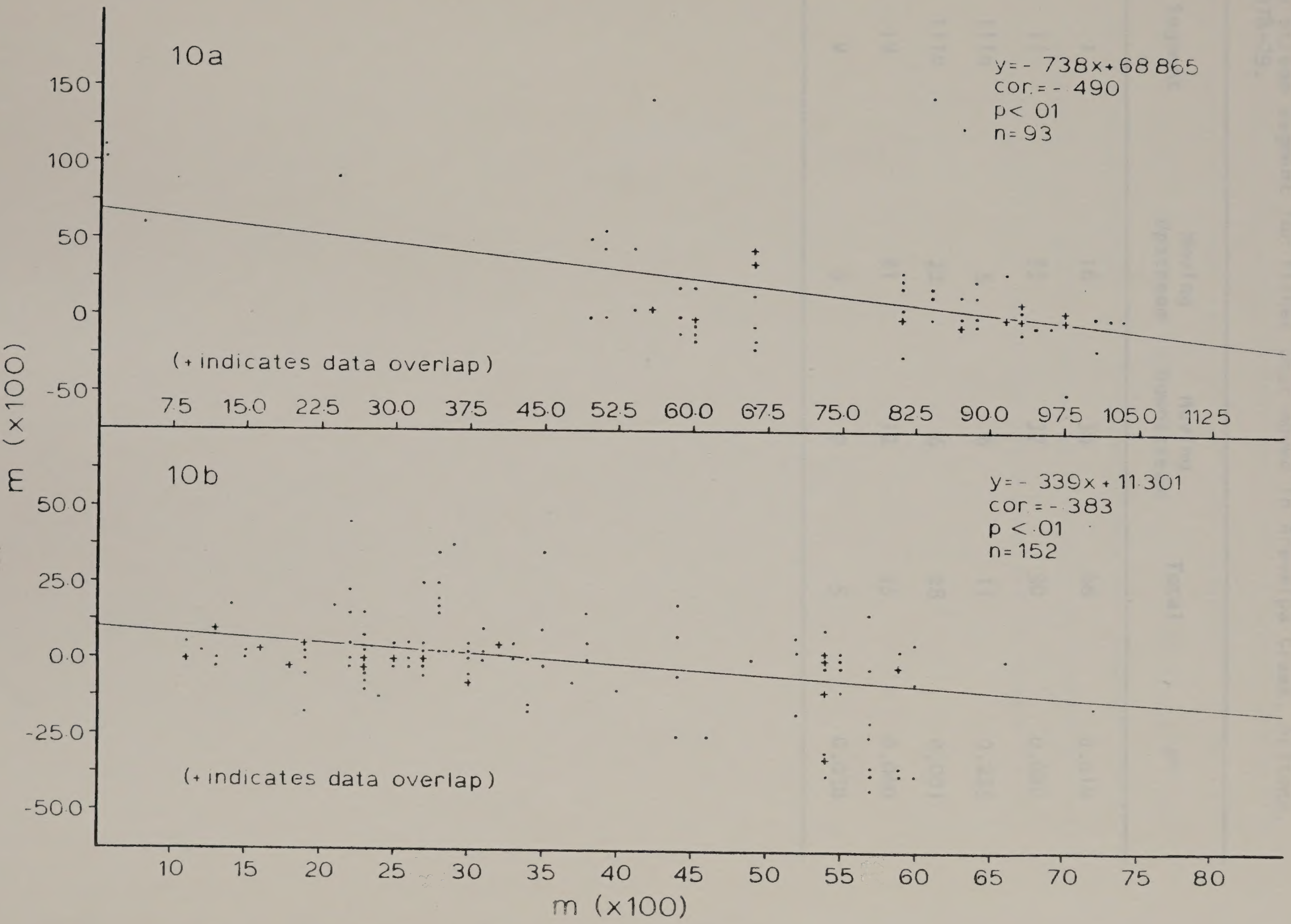

10a
y= -.738x+68.865
cor.= -.490
p<.01
n=93
(+ indicates data overlap)
150
100
50
0
-50
7.5
15.0
22.5
30.0
37.5
45.0
52.5
60.0
67.5
75.0
82.5
90.0
97.5
105.0
112.5
m (x100)
10b
y= -.339x + 11.301
cor.= -.383
p <.01
n=152
(+ indicates data overlap)
50.0
25.0
0.0
-25.0
-50.0
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
m (x100)

FIGURE 10. Summary information for regression analysis of distance moved (m x 100) by fishes relative to tagging locality: a) lower Granite Creek and b) upper Granite Creek.

TABLE 4. Summary of Bernoulli trial analyses for direction of movement by stream segment for fishes that moved in Aravaipa Creek, Arizona, 1978-79.

Segment	Moving Upstream	Moving Downstream	Total	p*
I	16	30	46	0.014
II	53	37	90	0.020
IIIa	5	6	11	0.225
IIIb	22	6	28	0.001
IV	21	12	33	0.040
V	5	0	5	0.030

moved in opposite directions, upstream in late winter through summer and downstream during summer-winter transition. Although sample size hinders analysis in later parts of the study, especially in the lower reaches, Bernoulli trials of seasonal trends in direction demostrates patterns that are scarcely due to chance (Table 5). Seasonal trends of direction and the opposing nature of movements of individual fish in different sections of the stream are emphasized in Figures 11-13.

TABLE 5. Summary of Bernoulli trial analysis for seasonal direction of movement of fishes that moved in Aravaipa Creek, Arizona, 1978-79.

Species	Season	Upper				Lower			
		Moving up	Moving down	n	p*	Moving up	Moving down	n	p*
Gila robusta	late winter 1978	4	13	17	0.018	7	3	10	0.117
	late summer 1978	11	1	12	0.003	2	2	4	0.375
	late winter 1979	9	5	14	0.122	--	--	--	-----
Pantosteus clarki	late winter 1978	4	16	20	0.005	10	13	23	0.136
	late summer 1978	18	11	29	0.060	2	0	2	0.250
	late winter 1979	3	4	7	0.273	--	--	--	-----
Catostomus insignis	late winter 1978	5	10	15	0.092	28	10	38	0.002
	late summer 1978	2	2	4	0.375	3	0	3	0.125
	late winter 1979	2	3	5	0.312	--	--	--	-----

TABLE 5. Concluded.

		Upper				Lower			
Species	Season	Moving up	Moving down	n	p*	Moving up	Moving down	n	p*
All fishes combined	late winter 1978	13	39	52	0.0001	45	26	71	0.007
	late summer 1978	31	14	45	0.005	7	2	9	0.070
	late winter 1979	14	12	26	0.144	--	--	--	-----

FIGURE 11. Times, distances (m X 100), and directions of movements of Gila robusta in Aravaipa Creek, Arizona, 1978-79. Mid-point of vertical axis represents point at which fish was tagged; upstream movement depicted by arrow pointing upward; downstream movement represented by downward-directed arrow; horizontal axis comprises months of study; position of arrow on last axis indicates time at which fish was marked; and length indicates period over which movement occurred.

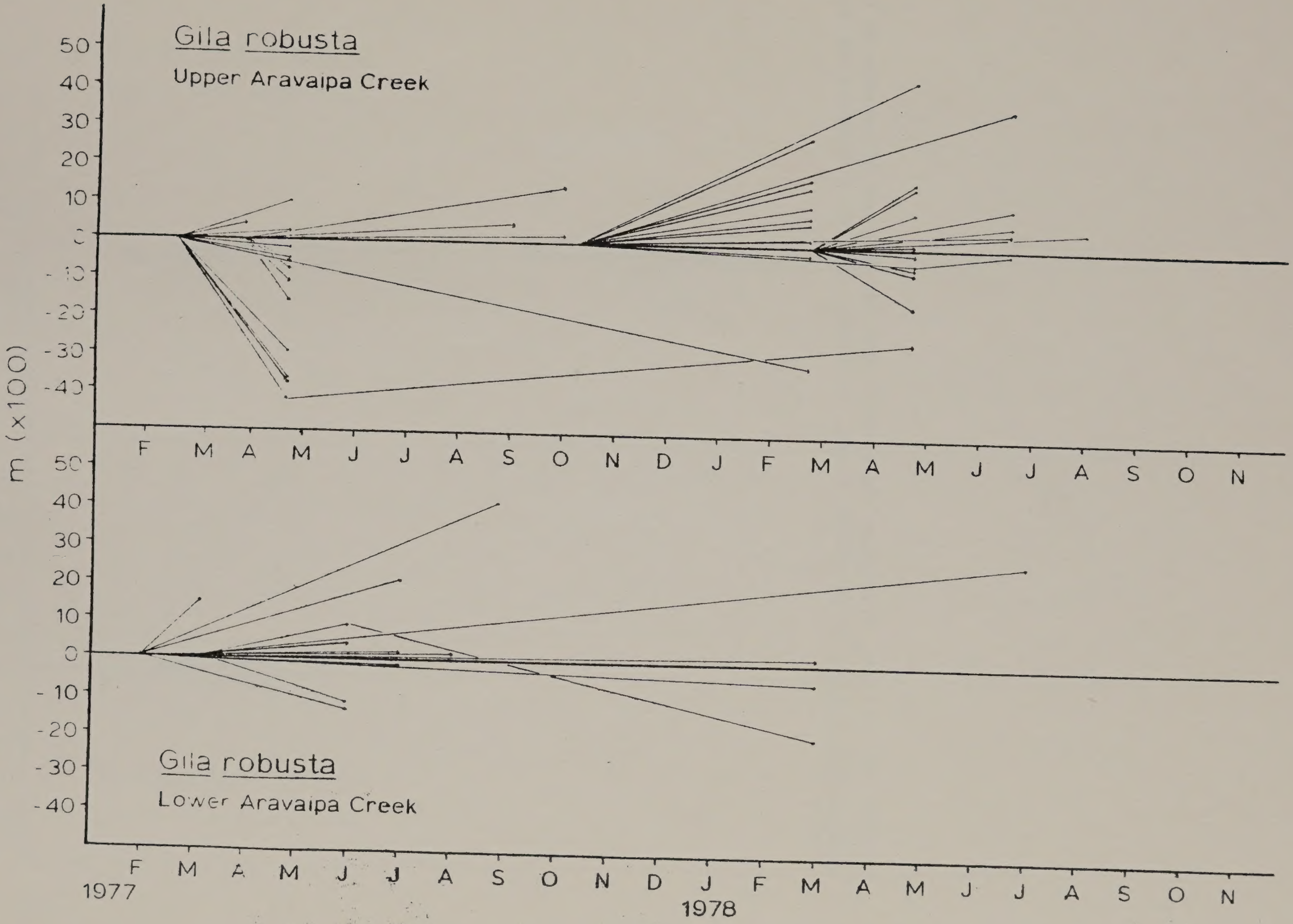

Gila robusta
Upper Aravaipa Creek
50
40
30
20
10
0
-10
-20
-30
-40
m (x100)
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
50
40
30
20
10
0
-10
-20
-30
-40
Gila robusta
Lower Aravaipa Creek
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
1977
1978

FIGURE 12. Times, distances (m X 100), and directions of movements of *Pantosteus clarki* in Aravaipa Creek, Arizona, 1978-79. Symbols as in Figure 11.

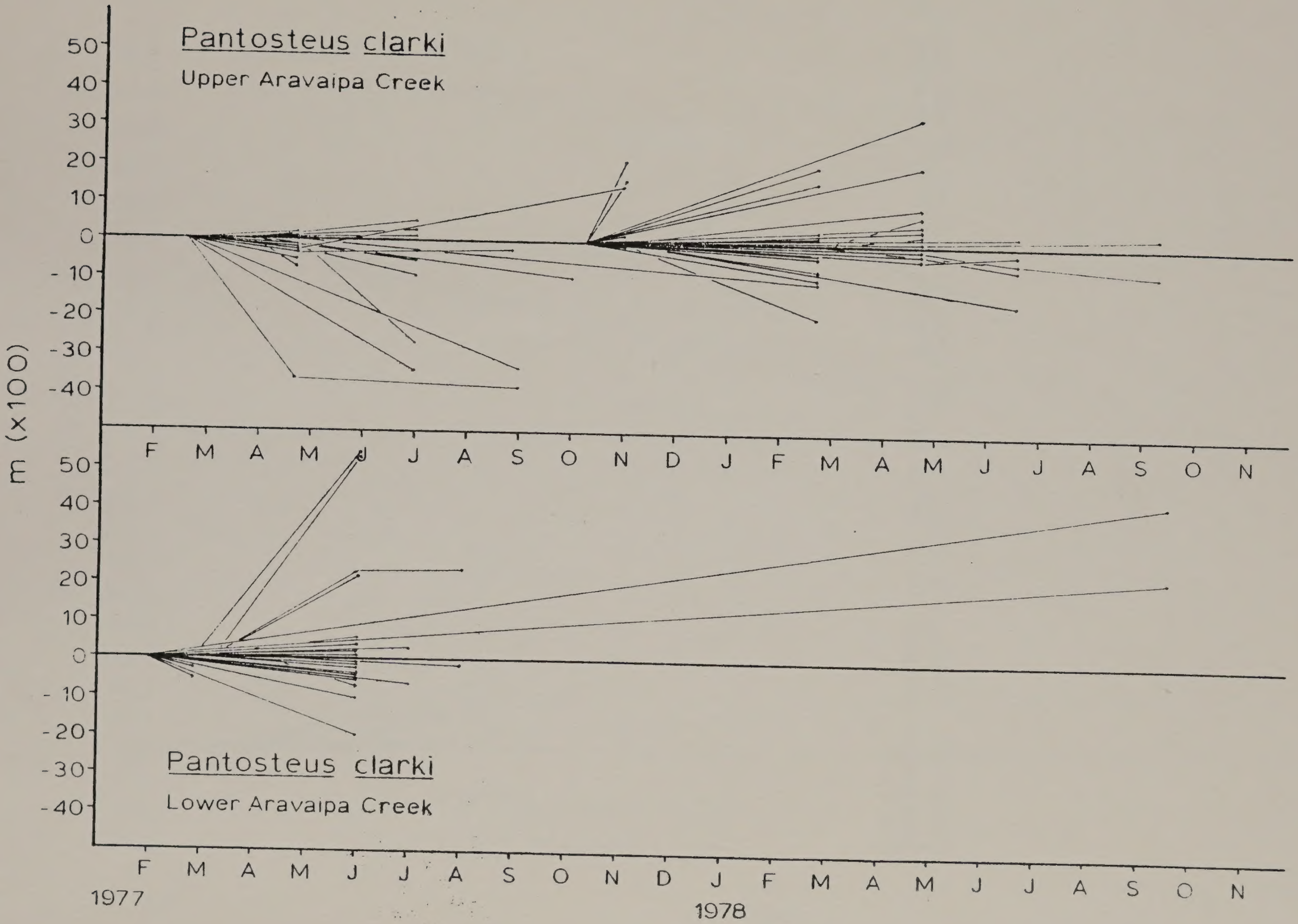

Pantosteus clarki
Upper Aravaipa Creek
Pantosteus clarki
Lower Aravaipa Creek
m (x100)
50
40
30
20
10
0
- 10
-20
-30
-40
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
1977
1978

FIGURE 13. Times, distances (m X 100), and directions of movements of *Catostomus insignis* in Aravaipa Creek, Arizona, 1978-79. Symbols as in Figure 11.

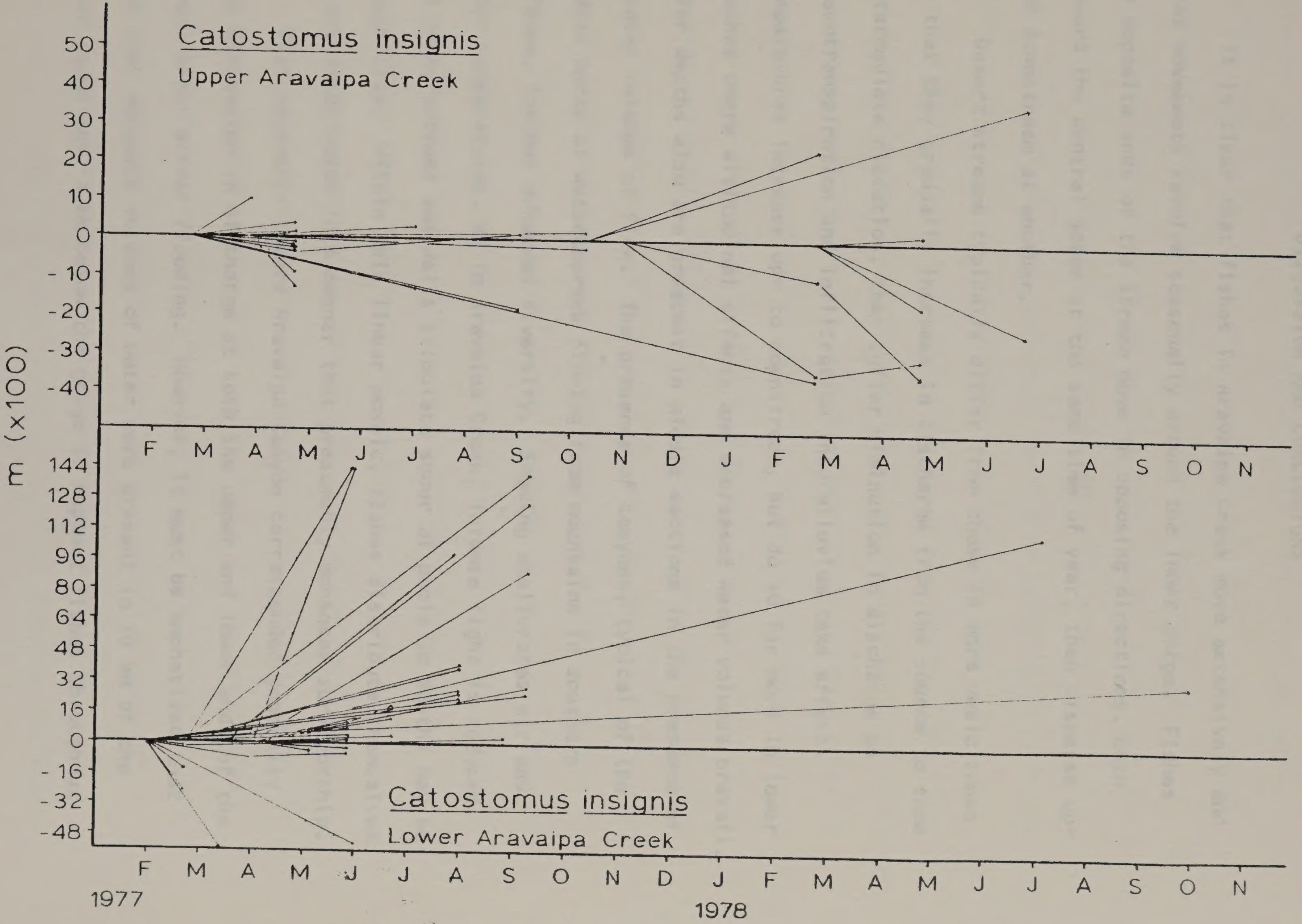

Catostomus insignis
Upper Aravaipa Creek
50
40
30
20
10
0
- 10
-20
-30
-40
m (x100)
F M A M J J A S O N D J F M A M J J A S O N
144
128
112
96
80
64
48
32
16
0
- 16
- 32
- 48
Catostomus insignis
Lower Aravaipa Creek
F M A M J J A S O N D J F M A M J J A S O N
1977
1978

FIGURE 16. Times, distances (m x 100), and directions of movements of *Catostomus insignis* in Aravaipa Creek, Arizona, 1978-79. Symbols as in Figure 15.

DISCUSSION AND CONCLUSIONS

It is clear that fishes in Aravaipa Creek move extensively and that movements revolve seasonally around the inner gorge. Fishes in opposite ends of the stream move in opposing directions, both toward the central gorge at the same time of year, then disperse up- and downstream at another.

Desert streams typically differ from those in more mesic zones in that they gradually increase in discharge from the source to some intermediate elevation, then suffer diminution in discharge as evapotranspiration and infiltration into alluvium take effect. Temperatures increase up- to downstream, but do so far more in lower reaches where altitudinal effects and decreased water volumes prevail. Water depths also are greatest in middle sections in the presence of greater volumes of flow. The presence of canyons, typical of the middle parts of watercourses flowing from mountains in southern Arizona, further enhances diversity. Shading ameliorates air and water temperatures, as in Aravaipa Creek, intense light is reduced, and rocky bottoms and walls stimulate scour of pools so depths may be exaggerated. Within this linear mosaic, fishes distribute themselves or are distributed in a manner that presumably enhances survivorship.

Fish movements toward Aravaipa Canyon corresponded generally with diminution in discharge at both the upper and lower ends of the stream after winter flooding. However, it must be emphasized that more than adequate volumes of water were present in 10 km of the upper reach and 14 km below the gorge to support fishes throughout

the year. The source rises abruptly and is relatively constant in position, whereas the point where water re-enters alluvium downstream varies a few hundred meters in position through the seasons.

Fishes remained within the gorge during summer floods, and on the basis of this, commonly held ideas concerning effects of flood on fishes border on unproven dogma. It would seem counterproductive for fishes to comgregate in the gorge where flood impacts must be exaggerated by constraining walls and thus be most severe. Yet they passed into or out of that reach during times of year when probabilities of flooding were highest (Fig. 3), seemingly ignoring such events. A massive flood in mid-December 1978 (Fig. 2) uprooted riparian trees more than a meter in diameter and transported them away. That flood was larger than any recollected by residents of more than 60 years, yet it, and another in early March 1978, made no apparent differences in patterns of dispersion and movement by fishes studied. Gerking (1950) similarly found stream fishes to be little if at all displaced by flooding in Indiana, and Deacon and Minckley (1974) could find few references indicating destruction or significant modifications of native Southwestern fish faunas by flooding.

A causal connection between drought or flood and patterns of movement is thus problematical in Aravaipa Creek. Drought conditions, if producing a retreat of source and lower end of the system toward the middle, would obviously force movements, but the origin remained stationary and the downstream sink moved less than a kilometer. Floods would necessarily have to stimulate movements in opposite directions in upper and lower segments, and also in different seasons

within the same reach. These factors are thus rejected as major forces influencing observed patterns of movement by fishes in Aravaipa Creek.

Little is known of orientation to temperature by fishes in nature, but it has long been established that they possess a preferred range. If presented with a thermal gradient, a fish selects a point(s) within a given range and remains there. Ortho- and klinokinesis have been proposed as mechanisms for orientation by fishes in such systems (Harden Jones 1968). Fishes move more often when outside their preferred range, slowing or stopping once that range is attained (Sullivan 1954). Temperature does not necessarily act as a directive force in small streams, since large daily fluctuations and local heterogeneity may preclude that phenomenon, but it does provide a gradient for selection of preferenda (Brett 1956). Receptors on the body surfaces and in the acousticolateralis system are amazingly sensitive to thermal changes, and discrimination capabilities are high (Bull 1936, Breder 1951, Collins 1952).

Aravaipa Creek, except in periods of seasonal transition, presents a complex series of thermal gradients. Daily and seasonal minima and maxima are decidedly lower within the canyon, and the bi-directional gradient from the canyon to each end of the stream is of rising temperature. Caution must be exercised when stressing thermal maxima in aquatic habitats as they have been shown to possess extraordinary heterogeneity (Young and Zimmerman 1956, John 1964, Minckley and Barber 1971, Deacon and Minckley 1974). Yet in summer, when values in Aravaipa Gorge are likely to be 2 to 8° C cooler than outside, waters above and below the gorge attain and in some instances exceed

lethal temperatures for some of the fishes. Deacon and Minckley (1974) reported moribund and dead loach minnow (Tiaroga cobitis Girard) in lowermost Aravaipa Creek at 30.5° C, and noted dying roundtail chub near that same temperature at another locality in Arizona. Although anecdotical, long-term residents along Aravaipa Creek stated that fish die-offs have frequently occurred in lower reaches in summer, presumably due to high temperatures. Riparian gallery shade may provide some thermal relief in limited areas, and stratification in the few largest and deepest pools also may be available. However, Aravaipa Creek was found surprisingly uniform in temperature by Minckley (1980), and especially so in the lower portion, and it is doubtful that microhabitat differentials afford sufficient situations for relief from stressful or uncomfortable conditions for large numbers of fishes. Thus, little recourse seems available other than seeking ameliorating conditions within the canyon in summer.

Segments I and V were essentially fishless in summer except for longfin dace (Agosia chrysogaster Girard), a small cyprinid fish capable of withstanding hot, severe conditions (Minckley and Barber 1971), and juveniles of larger species. Local residents substantiate the general absence of large suckers and "Verde trout" (the last a local vernacular for Gila robusta) in lowermost reaches of the stream in summer and their abundance in winter. Fishes in Segment V must move great distances to attain the gorge, and it is doubtful that all travel that far. A few deep, protected pools between Segment V and the gorge contained fishes year around. Although these habitats were too deep to sample with available equipment, a number of tagged

individuals of indeterminate origin were observed from the banks in July of both 1978 and 1979.

Wintertime temperatures are not likely to approach lethality anywhere in Aravaipa Creek, but those outside the gorge are warmer, especially in above-gorge reaches where inflow from the aquifer maintains relatively warm conditions on even the coldest nights (Fig. 4). Thus fishes may seek warmer areas outside the gorge in winter. Segments I and III through V abounded with all fish species in winter. Suttkus and Clemmer (1979) indicated a similar wintertime situation in the Colorado River above Grand Canyon, Arizona. That stream now receives hypolimnic water from Lake Powell at a relatively constant temperature of 7 to 10° C (Kubly and Cole 1979). Flannelmouth suckers (Catostomus latipinnis Baird and Girard) remained in a tributary, the Paria River, so long as its water temperature remained higher than that of the mainstream. When temperature in the Paria dropped below that of the Colorado, the suckers moved to the larger stream. In such instances, orthokinetic movements stimulated by temperatures outside a preferred range accounts for a net movement of fishes to a particular place along a gradient. Travel simply may slow or stop in the reach possessing a more favorable (preferred) range.

Factors other than temperature may bear upon patterns of movement by fishes in Aravaipa Creek. Water is normally clear and shallow in the system, and insolation is intense in open areas. All fishes of the genus Gila appear to actively avoid sunlight (Deacon and Minckley 1974), and probably do other fishes in deserts. Injurious sunburn has been documented for desert species (Minckley and Itzkowitz 1967,

Minckley and Barber 1971), and is known in trouts and other fishes under hatchery conditions (Corson and Brezosky 1961). Death may result from sunburn or secondary infections, with the difference being of little consequence. Light may thus stimulate or force movement to shade, and Aravaipa Canyon is the most extensive part of that stream that is reliably shaded.

Light as a permissive factor could only reinforce thermal effects. Intensity may be too high to permit residency in outside-gorge places in summer, and orthokinesis may again be suggested as the mechanism by which gorgeward movements are achieved. In situ separation of these factors is presently infeasible since Minckley (1980) demonstrated light and thermal regimes in the stream to be so intimately related as to be functionally interchangable. It is possible that one of these factors provides the primary stimulus to move and the other the perferendum at which movement is terminated.

Reproductive activities obviously stimulate movement in some fishes, but it is doubtful that procreative urgings are responsible for events observed in Aravaipa Creek. Observations on documented (Raney and Webster 1942) and supposed (Suttkus and Clemmer 1979) spawning runs of catostomid fishes indicate travel upstream and then relatively rapid drift downstream after the reproductive act, a pattern scarcely characterizing suckers in Aravaipa Creek. Circumstantial evidence against a causal relationship between reproduction and movements was strongest in 1978. During the typical spawning season, February-May (Minckley 1980), movements were directed into Aravaipa Gorge by fish in both upper and lower reaches. In the following

autumn, October-November, catostomids in the stream again attained spawning condition, and presumably reproduced at a time when movements were directed out of the gorge.

Movements of fishes in Aravaipa Creek in an apparently highly directed manner relative to the central gorge may imply other than orthokinetic mechanisms. Yet other hypothesis, such as imprinting that has been demonstrated as important in guiding sunfishes and salmons to a "home" area (Donaldson and Allen 1958), encounter difficulties. Movement downstream would have to be unguided (if a cue existed) until a destination had been reached or passed, since sensory sampling of downstream environments is impossible. A more direct genetic control of direction of movements also might be advanced. Conditions in desert streams are certainly harsh enough to be strong selective forces, and more salubrious conditions within the canyon could be advantageous. However, movements in opposing ends of the creek are in opposite directions, requiring two stocks. Small size of the stream and the fact that some tagged fishes traversed essentially the entire system obviously negate this possibility.

Home ranges, amply documented elsewhere for many stream fishes (Gerking 1950, 1953, 1959, Funk 1957, Gunning and Shoop 1962, 1963, and references cited), were indicated for only a few individual fishes in Aravaipa Creek. The stream is the epitomy of instability of substrate, with only those pools maintained by continuous scour against canyon walls remaining stable (present) through time. This was similarly observed by Turner and Karpiscak (1980) in the much larger Grand Canyon, where persistence of geologically-maintained pool habitats

was documented over time by paired photographs. Fajen's (1963) observations on influence of stream stability on home range and homing in smallmouth bass (Micropterus dolomieui [Lacepede]) are particularly pertinent. He concluded that smallmouth showed little tendency for home range in an unstable area, but did so in stable places. Few fishes in Aravaipa Creek could thus be expected to demonstrate the phenomenon, since cues such as pools required for homing are simply not present. Funk (1957) postulated a sedentary and mobile component within a species for stream fishes in Missouri, suggesting the sedentary group to be composed of intermediate-sized individuals. Regression of distance moved on total length in fishes from Aravaipa Creek failed to demonstrate a significant relationship (Fig. 14), and a sedentary group could not be identified with respect to size.

Of those few individuals included in a "stay-at-home" category in Aravaipa Creek (Fig. 6), 56% in the upper reach and 77% downstream showed no movement at all, being recaptured where tagged. This lack of even small movements may not be attributed to sampling bias favoring larger movements since entire reaches were sampled on a given date. Data from the most permanent pools provided evidence for the existance of at least some home ranges in the system. Mean time of residency of fishes in one stable pool against a cliff was 146.6 ± 117.7 days (n = 10). Several individuals stayed longer than 6 months; one remained 372 days. Mean time of residency in pools not maintained by scour against canyon walls was only 89.4 ± 40.3 days (n = 10). The longest occupation by any fish in one of the latter pools was 185 days. All other fishes remained less than 100 days.

FIGURE 14. Summary information for regression analysis of distance moved (m X 100) and total length of fishes in Aravaipa Creek, Arizona, 1978-79.

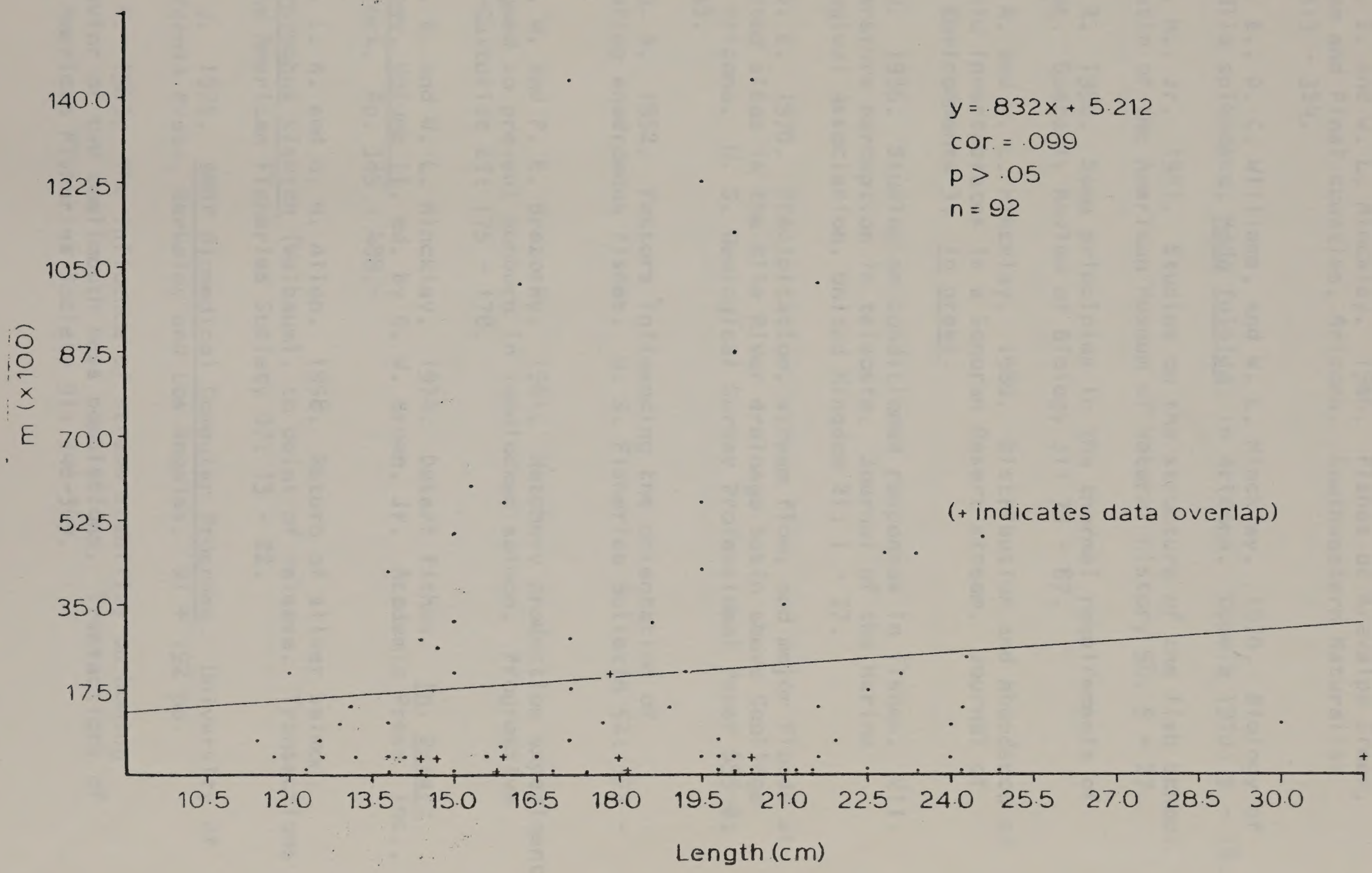

y = ·832x + 5·212
cor. = ·099
p > ·05
n = 92
(+ indicates data overlap)
m (x100)
140·0
122·5
105·0
87·5
70·0
52·5
35·0
17·5
10·5
12·0
13·5
15·0
16·5
18·0
19·5
21·0
22·5
24·0
25·5
27·0
28·5
30·0
Length (cm)

FIGURE 1. Summary information for regression analysis of stomach volume (n = 100) and total length of fishes in Aravaipa Creek, Arizona, 1978-79.

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